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THÈSE
présentée par

Aysegul SARAC

Pour obtenir le grade de Docteur
de l'Ecole Nationale Supérieure des Mines de Saint-Etienne

Spécialité : Génie Industriel

Modélisation et aide à la décision pour l'introduction des technologies RFID dans les chaînes logistiques

soutenue à Gardanne le 26/04/2010

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Thèse préparée dans le Centre Microélectronique de Provence Georges Charpak de l'École des Mines de Saint-Etienne

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« Tüm eğitimim boyunca bana verdikleri maddi ve manevi desteklerinden dolayı anneme, babama gönülden teşekkürlerimi sunarım. Eğitimimi Fransa'da sürdürmem için maddi ve manevi desteğini benden esirgemeyen Gülay ablama ve tavsiyeleri ve desteğiyle her zaman benim yanımda olan Güliz ablama sonsuz teşekkürler. Fransa'da yaşadığım sürede her zor anımda telefonun diğer ucunda olduğunuz için teşekkür ederim. »

Aysegul Sarac
Gardanne le 26/04/2010

To my family (aileme)...

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CHAPTER 1

RÉSUMÉ (SUMMARY IN FRENCH)

1.1 Contexte Scientifique

1.1.1 Les chaînes logistiques

Une chaîne logistique est l'ensemble de toutes les activités liées directement ou indirectement à la création d'un produit ou d'un service, afin de satisfaire la demande des clients. Une chaîne logistique peut être constituée par un ou plusieurs acteurs. On peut citer : les fournisseurs, les fabricants, les distributeurs, les détaillants et les clients, etc. La figure 1.1 illustre un modèle de chaîne logistique.

A l'intérieur d'une chaine logistique, chaque acteur cherche a maximiser sa rentabilité. L'objectif d'une chaîne logistique est donc de procurer une rentabilité maximale à tous ces acteurs. Avec la mondialisation, la compétition entre les entreprises est accrue. Afin de maintenir ou de renforcer leur position sur le marché, les sociétés doivent assurer :

1. une satisfaction client de haut niveau,
2. un coût le plus bas possible,
3. un délai le plus court.

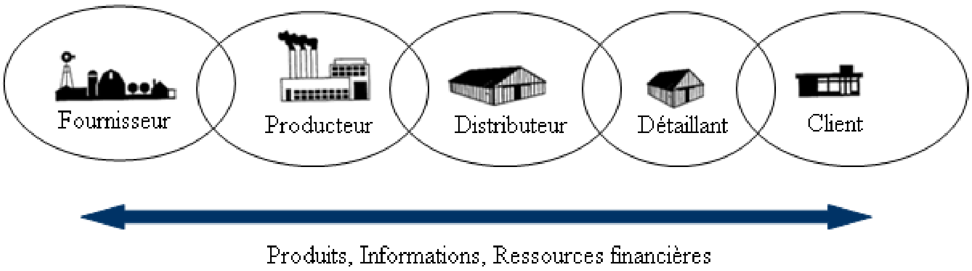


Figure 1.1: Un modèle de chaîne logistique

Cependant, ces objectifs sont souvent antagonistes. Par exemple, (2) implique d'avoir un minimum de stock, alors que (3) demande d'avoir un stock maximal pour la satisfaction client.

Les principaux facteurs clés pour réaliser ces objectifs (1),(2),(3) sont :

- la qualité de l'information,
- la fiabilité de l'inventaire,
- le contrôle physique des stocks.

La qualité de l'information :

Afin de répondre efficacement à la demande client, les acteurs de la chaîne doivent avoir le bon produit, au bon endroit et au bon moment. Pour ce faire, il est très important d'avoir un système fournissant des informations fiables. Une bonne information permet de ne pas se tromper de produit, d'avoir la bonne information sur la place géographique du produit, et ainsi de réduire le temps de déplacement. La qualité de l'information est donc un élément critique. Il existe différentes technologies permettant d'obtenir des informations fiables et en temps réel sur toutes les activités et les données des chaînes logistiques.

La fiabilité de l'inventaire :

La plupart des entreprises utilisent les systèmes d'information pour avoir une bonne visibilité de produits. Mais la performance de ces systèmes d'information est fortement dépendante de la fréquence des mises à jour. Il y a alors un écart entre le niveau de stock informatisé et celui des stocks réels. Cet écart représente la fiabilité de l'inventaire. Il existe plusieurs causes à cet inexactitude de l'inventaire. On peut citer entre autres: les erreurs de lecture, de livraison, ou de facturation, les fraudes, les vols, les produits mal placés, abîmés ou périmés. Les conséquences de ces inexactitudes ne sont pas des moindres. La plus importante est la rupture de stock (inattendu), causant ainsi une perte financière (perte du potentiel de vente, donc diminution des profits), mais aussi une perte du niveau de service (non respect des délais).

Le contrôle physique des stocks :

Nous venons de voir ci-dessus les effets de l'inexactitude de stock sur la chaîne logistique. Il est donc très important d'aligner le niveau de l'inventaire des stocks (informatiquement) avec celui des stocks réels. Un moyen très efficace est de faire le contrôle physique des stocks (réel). Cependant, comme dit plus haut, une bonne fréquence de mise à jour n'est pas assurée avec les technologies d'identification actuelles (par exemple, les codes-barres) (temps considérablement long ou coût opérationnel élevé).

Au vu de ces 3 points clés, nous pouvons dire que pour améliorer les performances, il faut avoir des informations correctes, en temps réel ainsi qu'une bonne visibilité des stocks. Au cours de ces dernières années, les technologies d'identification par radiofréquence (RFID) ont présenté un intérêt considérable comme solutions possibles des problèmes de chaîne logistique.

1.1.2 Les technologies RFID

1.1.2.1 Qu'est-ce que la RFID ?

C'est une des technologies d'identification automatique qui fonctionne sans contact par des fréquences radio. Un système RFID est composé de trois éléments :

- Un tag ou étiquette formé d'une puce reliée à une antenne. Selon le besoin des utilisateurs des technologies RFID, il est possible de tagger les objets aux niveaux des produits, des palettes, ou des moyens de transport.

- Un lecteur permettant l'émission ou la réception d'informations par signal radio. Les lecteurs peuvent être fixes ou mobiles.

- Un Middleware, qui contrôle et filtre les données récoltées par les lecteurs. C'est l'interface entre les données récoltées et les systèmes d'information de l'entreprise.

1.1.2.2 Pourquoi les technologies RFID sont-elles considérées comme une solution possible ?

Les technologies RFID présentent des avantages en comparaison aux technologies d'identification actuelles.

Meilleure identification individuelle :

Chaque puce RFID peut contenir un code unique qui permet d'identifier chaque produit. On a ainsi une visibilité complète des produits dans la chaîne logistique. Tandis que les codes-barres permettent d'identifier une seule classe de produits (capacité d'identification limitée).

Meilleure flexibilité de stockage :

Il est possible de modifier les données pendant la vie de la puce. Les étiquettes RFID proposent des applications efficaces pour suivre et enregistrer les différentes caractéristiques d'un produit pendant son cycle de vie. Les données des codes-barres ne peuvent pas être changées une fois qu'elles sont imprimées.

Information en temps réel et meilleure ergonomie :

Les technologies RFID fournissent une communication sans contact et en temps réel. Avec le processus de lecture par RFID, la fréquence des mises à jour est raccourcie (moins de temps pour lire tous les produits). Le fait d'être sans contact, permet de lire plusieurs objets à la fois, alors qu'avec une technologie de type codes-barres, il n'est possible de lire qu'un objet à la fois. Cette limitation du code barres est due à son mode de lecture (le code barres doit être "vue" par l'opérateur).

Pour conclure, les avantages principaux de RFID sur des technologies de codification à barres sont :

Identification:

- Possibilité d'identification individuelle des articles plutôt que des classes d'articles,
- Capacité de stocker plus de données,
- Possibilité de modifier les données.

Communication:

- Sans contact,
- Capacité de lecture multiple en parallèle,
- Aucune ligne de vue exigée.

Grace à leurs caractéristiques avancées d'identification et de communication, les technologies RFID peuvent fournir des informations correctes et en temps réel. Elles peuvent ainsi améliorer la valeur des informations, diminuer l'inexactitude de stock et faciliter le contrôle physique des stocks.

Les technologies RFID apportent de nombreux avantages dans les chaînes logistiques. Par contre, elles ne sont pas encore communes dans les entreprises.

1.1.2.3 Pourquoi observe-t-on quelques réticences à l'intégration des technologies RFID ?

Les sociétés hésitent à intégrer les technologies RFID dans leurs systèmes pour des raisons économiques et techniques.

Contraintes économiques :

L'intégration d'une nouvelle technologie exige des investissements considérables. D'autre part, elles sont toujours plus chères que les technologies d'identification actuelles.

Contraintes techniques :

Les environnements métalliques et liquides perturbent le fonctionnement de lecture. De plus, le manque de standards internationaux est un autre inconvénient (différentes normes et fréquences entre l'Europe et les Etas Unis).

Ainsi, ces obstacles rendent difficiles le déploiement massif des technologies RFID dans les entreprises et la comparaison entre avantages et incovénients de ces technologies.

1.2 Objectif de la thèse et aperçu des contributions

Dans cette thèse, nous nous concentrons sur l'intégration des technologies RFID dans les chaînes logistiques. La littérature dans ce domaine contient de nombreuses études qualitatives et quantitatives. En examinant la littérature nous constatons qu'il y a quatre approches principales :

- La plupart des publications considère les technologies RFID comme une technologie parfaite qui peut éliminer tous les problèmes de la chaîne logistique : Une technologie efficace à 100%.

- Nous remarquons aussi que ces études sont limitées pour donner une analyse complète de l'impact des technologies RFID sur les chaînes logistiques. La plupart des études simplifie les chaînes logistiques : un niveau, une période, un type de produit, etc.

- La plupart des études développe les modèles analytiques comme la méthode pour analyser l'impact des technologies RFID dans les chaînes logistiques. Ces modèles ne sont pas capables de fournir une analyse dynamique, ainsi ne sont pas efficaces en temps réel.

- Nous observons que la plupart des études considère l'intégration des technologies RFID comme remplacement pur et simple des codes-barres. Or, la chaîne logistique et tous les processus ont été conçus pendant de longues années par rapport aux caractéristiques et aux façons de fonctionner des technologies actuelles comme les codes-barres.

Dans cette thèse, nous considérons les technologies RFID comme non parfaites. Suivant les systèmes RFID mis en place on obtient des efficacités différentes. Par des modèles analytiques et de simulation, nous analysons comment les technologies RFID affectent la performance des chaînes logistiques en termes de satisfaction client, de niveaux de stock, de nombre de transport, etc. D'autre part, nous nous concentrons sur l'analyse économique, particulièrement les analyses de ROI (Return On Investment) pour comparer les avantages obtenus par des technologies RFID avec les coûts associés à l'intégration. Nous analysons aussi comment les avantages des RFID peuvent être améliorés dans des chaînes logistiques. Nous comparons les impacts d'intégration des technologies RFID aux chaînes logistiques en remplaçant juste les technologies d'identification actuelles et en réorganisant des chaînes logistiques utilisant les nouvelles possibilités fournies par des technologies RFID.

Dans cette étude, nous abordons la mise en œuvre des technologies RFID, par les questions suivantes :

- Comment peuvent-elles affecter les performances des chaînes logistiques en termes de satisfaction client, de gestion de stock, etc. ?

- Quels facteurs peuvent influencer leur performance dans les chaînes logistiques ?

- Quelle technologie est la plus efficace pour un certain type de produit ?
- Quel est le ROI pour les sociétés ?
- Quel est leur coût critique (coût variable + coût fixe) pour certains types de produit ?
- Comment les acteurs de la chaîne logistique peuvent-ils améliorer le profit obtenu ?
- Quels changements peuvent être effectués au niveau de l'organisation et du fonctionnement des chaînes logistiques dans le but d'améliorer leurs avantages ?

1.3 Plan de lecture

Cette thèse est organisée comme suit :

Le premier chapitre correspond à la description du contexte scientifique et des principaux axes des technologies RFID. Nous rappelons brièvement les principes d'une chaîne logistique et de fonctionnement d'un système simple basé sur la RFID. Nous discutons aussi des capacités potentielles et des limitations des technologies RFID dans les chaînes logistiques.

Le chapitre 2 propose un état de l'art sur les impacts de technologies RFID dans les chaînes logistiques. On considère la littérature en deux groupes principaux; papiers *"contenu-orientés"* et articles *"méthode-orientés"*. L'inexactitude d'inventaire, l'effet de "bullwhip" et les stratégies de réapprovisionnement sont les sujets principaux traités dans la littérature. Les modèles analytiques, les simulations, les études de cas et les expérimentations sont les méthodes principalement utilisées dans la littérature. Nous présentons aussi les travaux développant une analyse économique des technologies RFID par l'analyse du ROI.

Le chapitre 3 présente un modèle analytique afin d'évaluer les impacts des RFID sur la gestion des stocks. Nous comparons deux modèles de "vendeur de journaux". Le problème de "vendeur de journaux" est un modèle analytique classique qui se concentre sur des articles saisonniers avec des cycles de vie courts ou des demandes saisonnières. Un vendeur de journaux détermine chaque jour combien de copies d'un journal doivent être achetées, (chaque copie vendue fournissant un bénéfice et chaque copie non vendue causant une perte [32]). Ainsi, l'objectif principal de ce modèle est de décider la quantité de commande optimale pour maximiser le bénéfice. Dans la modélisation du "vendeur de journaux", les décisions de commande sont faites avant la saison de vente. Le vendeur doit empêcher deux situations : le surstock et la rupture de stock. Si la quantité de commande est supérieure à celle de la demande, toutes les marchandises non vendues à la fin de la saison de vente sont vendues à un prix au-dessous du prix de vente. La demande insatisfaite correspond aux ventes perdues et il y a un coût de pénalité. Notre premier modèle de vendeur de journaux est développé pour analyser un système de stock à une période contenant plusieurs erreurs de chaîne logistique. Ces erreurs causent des ruptures de stock et diminuent ainsi le niveau de service clients et les ventes. Le deuxième modèle est basé sur le premier modèle, en intégrant différents systèmes RFID pour évaluer leur impact économique sur la gestion de stock.

Dans le chapitre 4, nous présentons une étude d'une chaîne logistique à trois niveaux par simulation à évènements discrets. Cette chaîne contient un fabricant, un centre de distribution et un détaillant. Nous considérons trois produits qui ont des prix et des demandes de client différents. Les produits sont approvisionnés par la stratégie ; le point de commande (s) et la quantité économique de commande (EOQ). Dans cette chaîne, le stock peut être erroné à cause des différentes erreurs de chaîne logistique. Ces erreurs causent l'inexactitude d'approvisionnement, la faible satisfaction client, les longs délais de livraison, etc. Nous considérons l'intégration de diverses technologies RFID avec différents niveaux d'utilisation pour un produit ou pour les produits multiples. Nous aspirons à d'abord analyser les impacts de la RFID sur le fonctionnement et l'économie de la chaîne logistique. Nous comparons ensuite les effets d'une intégration simple des technologies RFID et de réorganisation des chaînes logistiques. Nous utilisons la simulation par événements discrèts pour analyser les impacts des RFID sur le fonctionnement et les effets économique de la chaîne logistique pour chaque cas.

On donne la conclusion et des perspectives dans le dernier chapitre. Nous abordons les impacts des RFID sur des chaînes logistiques et une vue d'ensemble des défis et des avantages de l'intégration des technologies RFID dans des chaînes logistiques.

1.4 Simulation d'une chaîne logistique à trois niveaux

Nous considérons une chaîne logistique à trois niveaux avec un producteur, un distributeur et un détaillant. Le niveau de détaillant correspond en réalité à deux niveaux de stockage : la réserve et l'espace de vente du magasin.

La Figure 1.2 représente la chaîne logistique considérée. Les clients prennent une certaine quantité de produits des étagères du détaillant. Le détaillant passe commande au distributeur et stocke les produits reçus dans la réserve du magasin. Le détaillant peut satisfaire les demandes client tant que les articles sont disponibles sur les rayons. La capacité de stock des étagères est limitée. Les étagères sont remplies suivant une politique de point de commande ou par des requêttes des clients quand il y a rupture de stock. Au niveau supérieur, le distributeur fournit les produits du fabricant pour satisfaire les demandes du détaillant. Nous supposons que le fabricant n'a pas de contraintes de capacité de stock et peut ainsi toujours satisfaire les commandes du distributeur.

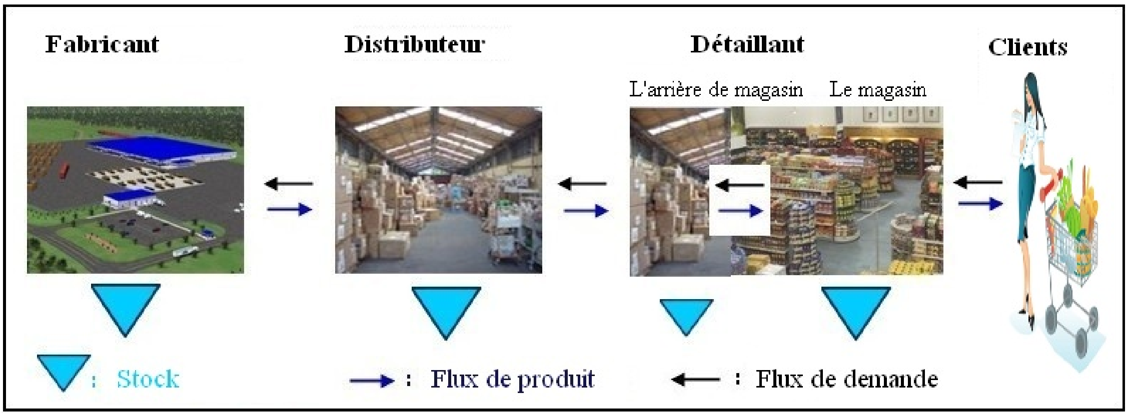


Figure 1.2: La chaîne logistique

Dans les chaînes logistiques, plusieurs types d'erreurs sur les stocks peuvent arriver. Dans cette étude, nous nous sommes principalement intéressés aux erreurs telles que les vols, les produits mal placés, les articles indisponibles (abîmés, périmés, etc.) et les erreurs de livraison. Ces erreurs incitent de fausses informations sur le stock qui influencent la performance et l'économie des chaînes logistiques en augmentant les ruptures de stock, les ventes perdues, les délais de livraison en diminuant ainsi la satisfaction client. Chaque acteur contrôle ses niveaux de stock par un comptage physique pour aligner les niveaux de stock réel aux données informatisées. La fréquence de comptage est définie à chaque niveau de stockage selon plusieurs facteurs comme les propriétés de produits, la durée d'inexactitude de stock (l'écart entre le niveau de stock informatisé et celui des stocks réels) et le temps et le coût de ce comptage.

1.4.1 Produits

Trois produits sont analysés, avec des prix différents et des demandes différentes de client (cf. figure 1.3). Pour analyser leur importance, nous avons utilisé la méthode de classification ABC. La classification d'articles est exécutée sur leur valeur annuelle et peut varier d'une société à un autre. Il y a trois groupes d'articles; A (très important), B (modérément important) et C (peu important). A titre d'illustration, les produits électroménagers sont de type A, les produits de beauté et de santé sont de type B et les produits de consommation courante sont de type C.

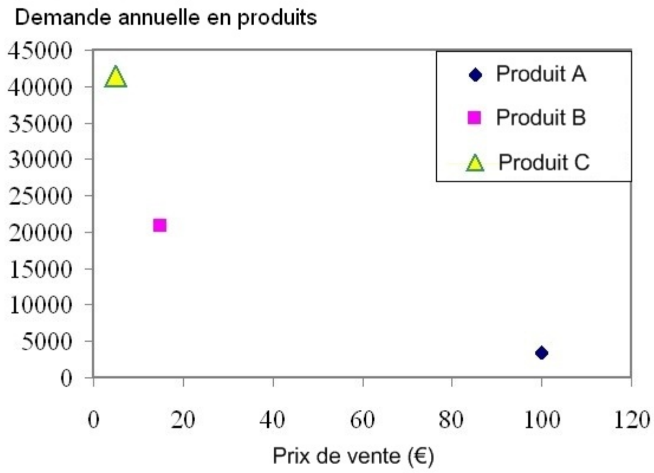


Figure 1.3: Exemple de la demande et prix des produits A, B et C

1.4.2 La politique de réapprovisionnement

Nous considérons que le détaillant et le distributeur fixent le point de commande (s) et la quantité de commande économique (EOQ) d'approvisionnement des stocks afin de satisfaire la demande client avec un minimum de coût de stockage et de transport. Le s dépend de la demande, du délai de livraison et du stock de sécurité. Le stock de sécurité est l'inventaire supplémentaire pour la protection du système contre les ruptures de stock possibles à cause de la variabilité des demandes et des délais de livraison. L'EOQ dépend du coût de commande, du coût de stockage et de la demande annuelle pour chaque produit.

Les valeurs du point de la commande (s) et de la quantité économique de la commande (EOQ) sont calculées pour des produits A, B et C et présentées dans le tableau 1.1. Ces paramètres influencent la performance des chaînes logistiques.

1.4.3 Modélisation de la chaîne logistique

Dans cette section nous modélisons le problème décrit ci-dessus en donnant les paramètres de simulation.

Produits		A	B	C
Etagère	s	1	2	4
	EOQ	6	20	50
Réserve du magasin	s	10	50	100
	EOQ	140	1000	2600
Centre de distribution	s	20	100	200
	EOQ	440	3050	8300

Table 1.1: Valeur des points de commande (s) et des quantités économiques de la commande (EOQ) pour des produits A, B et C

1.4.3.1 La demande du client

Nous présentons ici le modèle du comportement d'un consommateur lors de l'acquisition du produit. Dans notre exemple, le détaillant est ouvert 288 jours par an (de 9h00 à 21h00) et les clients viennent au magasin pour acheter des produits A, B ou C. Nous considérons que les temps d'arrivée entre deux clients sont exponentiellement distribués avec les moyennes 60 min, 10 min et 5 min pour respectivement les produits A, B et C.

Le client qui vient au magasin, va aux étagères pour chercher le produit.

- Si le client trouve le produit sur le rayon, il le prend et va à la caisse pour le payer.
- Lors d'une rupture de stock le client ne peut pas trouver le produit sur les étagères.
  - Il peut quitter le magasin sans acheter le produit.
  - Il peut chercher un employé pour demander le remplissage du rayon. Les clients peuvent choisir d'attendre jusqu'à ce que les étagères soient remplies. Nous considérons que le pourcentage de clients prêts à attendre le remplissage est différent pour chaque produit (60 % pour A, 50 % pour B et 40 % pour C).
  - Il peut quitter le magasin après un certain temps d'attente. Nous considérons que les clients attendent au maximum 10 min pour le remplissage du rayon.

Le niveau de stock physique des étagères diminue quand les clients prennent des produits, mais le niveau de stock dans le système informatisé diminue seulement quand les clients payent pour le produit à la caisse.

1.4.3.2 Le réapprovisionnement des stocks

Le détaillant remplit automatiquement les rayons selon les données dans le système d'information sur les niveaux de stock. Le détaillant ne peut pas automatiquement détecter les erreurs : différences entre le niveau de stock réel et celui du système informatisé qui peut causer les ruptures de stock. Dans le cas de rupture de stock sur rayon, les clients peuvent chercher un employé pour demander le produit.

- Si le client trouve un employé, l'étagère correspondante peut ainsi être remplie par les informations qui viennent du client données à l'employé.
- Sinon, Il quitte le magasin sans acheter le produit.

Les rayons peuvent être remplis tant que les articles sont disponibles dans la réserve du magasin. Après chaque remplissage d'étagère, le détaillant décide de commander les produits suivant la politique de commande (s, EOQ) basée sur les données du système d'information relative aux niveaux de stock.

Dans le centre de distribution, la procédure d'approvisionnement est semblable à celle de la réserve du magasin. On commande automatiquement des produits du fabricant sous une politique (s, EOQ) pour satisfaire les commandes du détaillant. Nous supposons que le fabricant n'a aucune contrainte de capacité de production et peut ainsi toujours livrer les produits au centre de distribution.

1.4.3.3 Le contrôle physique des stocks

Le détaillant et le distributeur mettent à jour leurs données sur les niveaux de stock dans le système d'information quand ils ont des ruptures de stock ou par un contrôle des stocks physiques qu'ils exécutent périodiquement sur une durée fixe. La fréquence du contrôle des stocks dépend des caractéristiques du produit, de la durée d'inexactitude de stock dans le système et le temps de comptage, etc. Les processus de gestion des stocks à chaque niveau de stockage sont réalisés périodiquement.

Le temps de contrôle des stocks dépend du niveau de stock et la taille de produits. Les acteurs de la chaîne logistique essayent de trouver la période optimale du contrôle du stock avec des contraintes de temps et de coût d'inventaire.

1.4.3.4 Les erreurs de la chaîne logistique

Dans notre modèle global de la chaîne logistique, nous prenons en compte différents types d'erreurs : vols, produits mal placés, articles indisponibles (abîmés, périmés, etc.) et les erreurs de livraison. Ces erreurs impliquent une différence entre le niveau de stock réel et le niveau de stock du système d'information ce qui peut mener aux ruptures de stock. Nous classifions ces erreurs en deux groupes et les présentons dans le tableau 1.2.

Groupe	Classe	Où ?	Comment ?	Combien ?
"*Shrinkage*"	Vols	Magasin	Externe	-
		Réserve du magasin	Interne	- -
		Distributeur	Interne	- - -
	Produits mal placés	Magasin	Externe	-
		Réserve du magasin	Interne	- - - - -
		Distributeur	Interne	- - - - - - - -
	Produits périmés ou abimés	Magasin	Unité	-
		Réserve du magasin	Palette	- - - - -
		Distributeur	Palette	- - - - - - - -
Livraison	Livraison désirée	Distributeur → Réserve du magasin	Palette	- - - - - - - -
		Distributeur → Réserve du magasin	Palette	+++++++
		Distributeur → Réserve du magasin	Camion	0
	Livraison aléatoire	Distributeur → Réserve du magasin	Camion	+++++++ +++++++

Table 1.2: Classification des erreurs dans une chaîne logistique

Les erreurs de "shrinkage" (vols, produits mal placés et articles indisponibles)

Dans notre modèle nous différencions les erreurs dues aux clients (externe) et les erreurs dues aux employés (interne). Dans le magasin, les vols et les produits mal placés sont considérés comme des erreurs dues au comportement du client. Le client qui vient au magasin va aux étagères pour chercher le produit.

- Si le client trouve le produit sur les étagères, il le prend et peut ensuite agir de trois façons.
    - Il peut aller à la caisse pour acheter le produit (client satisfait),

  - il peut changer d'avis et mettre le produit sur une autre étagère dans le magasin (produit mal placé),
  - il peut voler le produit (vol).

- S'il ne trouve pas le produit,
  - il peut quitter le magasin sans acheter le produit (client pas satisfait) ou
  - il peut chercher un employé pour demander le remplissage d'étagère.

Les mêmes erreurs arrivent aussi dans la réserve du magasin. Nous considérons que les produits peuvent être mal placés ou volés par des employés. De là, il peut y avoir des ruptures de stock dans la réserve du magasin, qui peut augmenter le retard de remplissage d'étagère et mener à la perte de ventes potentielles. Dans le centre de distribution, les mêmes erreurs peuvent arriver. Ces erreurs sont généralement causées par les salariés du distributeur.

Les ruptures de stock peuvent arriver à cause de ces erreurs. Dans cette étude, nous fixons les paramètres de simulation pour ces erreurs et nous nous concentrons sur ces paramètres. Ces paramètres dépendent de plusieurs facteurs, comme les caractéristiques des produits et des chaînes logistiques. Mais d'autres paramètres peuvent influencer la performance de la chaîne logistique.

Les erreurs de livraison

Les erreurs de livraison constituent un autre type d'erreurs des chaînes logistiques et peuvent causer des ruptures de stock. Elles peuvent arriver pendant toutes les livraisons entre chaque emplacement de stock. Nous considérons que les acteurs de la chaîne logistique commandent des produits à leur fournisseur par une politique (s, Q) utilisant les données du système d'information sur les niveaux de stock. Le producteur livre les produits au distributeur, le distributeur livre au détaillant et les produits sont livrés de la réserve du magasin aux rayons. Nous considérons que les erreurs de livraison peuvent arriver de deux façons principales; pendant des livraisons planifiées et pendant des livraisons non planifiées.

Quand un acteur commande les produits à son fournisseur, il y a quatre possibilités :

- il peut recevoir exactement le nombre de produits qu'il a commandés,
- il peut recevoir moins de produits que la quantité demandée,
- il peut recevoir plus de produits que la quantité demandée,

- ou il ne reçoit pas de produit après un certain temps d'attente.

Les acteurs peuvent réagir différemment :

- Quand un acteur reçoit exactement les produits commandés, il n'y a aucune erreur, il accepte la quantité reçue.
- Dans le cas des erreurs de livraison, nous supposons que les acteurs ne peuvent pas toujours détecter ces erreurs.
  - Si un acteur ne remarque pas la différence de quantité, il considère qu'il a reçu la quantité commandée.
  - S'il remarque la différence de quantité, les acteurs peuvent réagir à ces erreurs.
    - De même il acceptera la quantité reçue si c'est plus petit que la quantité demandée. Pour corriger l'erreur, l'acteur peut commander plus tôt la livraison suivante.
    - Quand il reçoit plus de produits que la quantité demandée, il doit prendre une décision pour accepter ou pas les produits en surplus.
      - Si après la livraison, le niveau de stock réel ne dépasse pas le niveau de stock maximal, il acceptera la quantité délivrée.
      - Si cette valeur est plus grande que le niveau de stock maximal, il refusera les produits en surplus. Chaque acteur a déjà défini le niveau de stock maximal pour chaque produit.

Une autre erreur de livraison peut arriver si le fournisseur oublie ou ignore la commande. Si l'acteur ne reçoit pas de produits après un certain temps d'attente, il annulera la commande et fera une nouvelle commande. Des temps d'attente maximaux ont été définis pour chaque acteur selon la moyenne des délais de livraison.

Nous considérons un autre type d'erreur. Les fournisseurs peuvent livrer par erreur quelques produits bien que leurs clients n'aient pas commandé les produits. Il y a différentes possibilités ; les produits livrés peuvent intéresser les clients, ou les produits ne concernent pas les clients.

- Si le client est intéressé par le produit livré, il peut accepter la livraison selon son niveau de stock.
  - Si la somme du niveau de stock et les produits reçus ne dépasse pas le niveau de stock maximal, il acceptera la quantité reçue.

  - Si cette valeur est au-dessus du niveau de stock maximal, il rendra les produits en surplus.

- Si les produits livrés n'intéressent pas le client, il refusera la livraison.

Dans cette étude, nous fixons les paramètres de simulation pour les erreurs de livraison et nous nous concentrons sur ces paramètres.

1.4.4 L'intégration des technologies RFID dans les chaînes logistiques

Pour analyser les impacts des RFID sur les chaînes logistiques, nous intégrons différentes technologies au système actuel. Nous nous concentrons sur cinq mises en œuvre différentes;

- en boucle fermée,
- au niveau des palettes,
- au niveau des produits,
- au niveau des produits avec plus de lecteurs,
- au niveau des produits avec des étagères intelligentes.

Dans cette section, l'intégration des technologies RFID considère la remplacement des technologies actuelles d'identification (c'est-à-dire des codes barres). Nous définirons six scénarios de simulation pour évaluer l'impact des mises en œuvre des diverses technologies RFID.

1.4.4.1 Différents scénarios

Comme nous l'avons déjà mentionné, divers systèmes RFID peuvent être obtenus en combinant différentes étiquettes, lecteurs, fréquences, niveaux de marquage, etc. Le coût et le bénéfice potentiel de chaque système peuvent changer. Nous considérons 6 différents scénarios qui représentent différentes technologies à différents coûts et éfficacités. La figure 1.4 illustre nos scénarios.

Scénario 1 : Système actuel, code barres

Dans le premier scénario, la technologie classique de codes à barres est utilisée pour identifier les produits. Ce scénario correspond au système actuel.

Figure 1.4: Les scénarios

Scénario 2 : RFID en boucle fermé

Des boîtes réutilisables contenant des étiquettes RFID sont utilisées seulement pendant le processus de livraison entre le producteur, le distributeur et le détaillant et sont renvoyées à l'expéditeur initial. Nous considérons que ces boîtes peuvent contenir 10 articles de produit A, 50 articles de produit B ou 100 articles de produit C et il y a 175 boîtes pour le produit A, 244 pour le produit B et 238 pour le produit C. Les nombres de boîtes sont calculés pour assurer que toutes les livraisons peuvent être réalisées en même temps.

Scénario 3 : RFID au niveau palettes

Les palettes sont préparés par le fabricant et chaque palette peut contenir 20 articles de produit A, 100 articles de produit B ou 200 articles de produit C. La technologie RFID dans ce scénario peut améliorer la visibilité et la traçabilité des palettes du fabricant au détaillant. Il peut diminuer les erreurs de livraison et peut réduire les vols, les produits mal placés et les articles indisponibles dans la réserve du magasin et au centre de distribution. Cependant, cette technologie ne peut pas affecter les erreurs dans le magasin, car les palettes sont ouvertes dans la réserve du magasin pour remplir des étagères. Dans ce scénario, la technologie RFID ne peut pas identifier des produits à l'extérieur des palettes. Ainsi, la visibilité des articles dans le magasin ne change pas et le détaillant a toujours les mêmes erreurs dans le magasin. D'autre part, comme les technologies RFID accélèrent le contrôle physique des stocks, les acteurs de la chaîne logistique peuvent augmenter la fréquence de contrôle des stocks physiques pour ajuster l'inventaire dans la réserve du magasin et au centre de distribution.

Scénario 4 : RFID au niveau produit

La visibilité des articles peut s'effectuer dans ce cas dans le magasin. Les niveaux de stock peuvent être vérifiés fréquemment dans la chaîne logistique complète. Cette technologie est capable de diminuer tous les types d'erreurs rencontrés dans la chaîne logistique.

Scénario 5 : RFID au niveau produit avec plus de lecteurs

Dans ce scénario, nous considérons un system RFID au niveau des articles qui contient deux fois plus de lecteurs que dans le scénario 4 et ainsi qui est plus efficace que le système RFID du Scénario 4.

Scénario 6 : RFID au niveau produit avec "smart shelves"

Nous ajoutons des étagères intelligentes au scénario 5. Ces étagères peuvent faire l'inventaire fréquemment (par exemple chaque minute) et automatiquement. Cette technologie fournit ainsi les informations en temps réel au niveau de l'article dans le magasin.

1.4.5 Intégration simple des technologies RFID dans les chaînes logistiques

Tous les scénarios sont simulés avec le logiciel Arena (version 11) pour chaque produit séparément sur trois ans et sont répétés 100 fois pour stabiliser les modèles. Nous présentons d'abord les indicateurs de performance qui sont utilisés pour analyser les impacts des technologies RFID sur les modèles étudiés. Ensuite, les résultats et les analyses de retour sur investissement (ROI) sont analysés séparément.

1.4.5.1 Les indicateurs de performance de la RFID sur la chaîne logistique

Pour analyser les simulations, nous nous basons sur les indicateurs de performance correspondant aux quantités suivantes :

- nombre de tags utilisés,
- nombre de ventes,
- nombre de ventes perdues,
- nombre de produits perdus,

- nombre de livraisons entre le fabricant, le distributeur et le détaillant,
- nombre d'inventaires,
- niveaux de stocks chez le distributeur et le détaillant.

Nous analysons ces indicateurs de performance pour répondre à deux questions :

- Comment les technologies RFID influencent la performance de la chaîne logistique,
- Quels sont leurs impacts économiques ?

Influence des RFID sur la performance des chaînes logistiques

Les RFID peuvent améliorer les processus opérationnels comme la réception et la préparation des produits, l'approvisionnement des stocks, la livraison, l'inventaire, etc. Elles peuvent aussi diminuer les erreurs dans la chaîne logistique. Ces améliorations aident à augmenter le nombre de produits vendus et diminuer le nombre des clients non satisfaits qui quittent le magasin sans acheter le produit en réduisant la rupture de stock.

L'impact des technologies RFID peut être évalué en utilisant une mesure de satisfaction client exprimée en pourcentage, comme le nombre de clients qui achètent en réalité le produit (les clients satisfaits) comparé au nombre de clients potentiels qui veulent acheter le produit (nombre des clients satisfaits et des clients non satisfaits).

Impacts économiques des technologies RFID

Pour analyser les impacts économiques de chaque technologie, les profits totaux de la chaîne logistique peuvent être comparés. Nous pouvons calculer les profits par le revenu moins les coûts des articles volés et des articles indisponibles, les coûts de livraison, les coûts de stock, les coûts des inventaires, les coûts des technologiques et autres coûts fixes de la chaîne logistique.

Les acteurs de la chaîne logistique peuvent tirer profit tant qu'ils vendent des produits.

Le coût d'articles perdus est calculé par le nombre des articles perdus dans la chaîne logistique à cause du vol et des articles indisponibles à la vente (les produits abîmés, périmés, etc.). S'il y a des articles perdus dans le système, les acteurs perdraient les prix d'achat de ces produits.

Pour chaque livraison, les acteurs payent un coût de livraison. Le coût de la livraison augmente par les retours de livraison qui arrivent à cause des erreurs de livraison.

Il y a un coût de stockage pour chaque produit stocké dans la chaîne logistique.

Pour chaque contrôle physique des stocks, les acteurs payent un coût qui dépend du temps de comptage des stocks et du nombre d'employés utilisés pour faire l'inventaire.

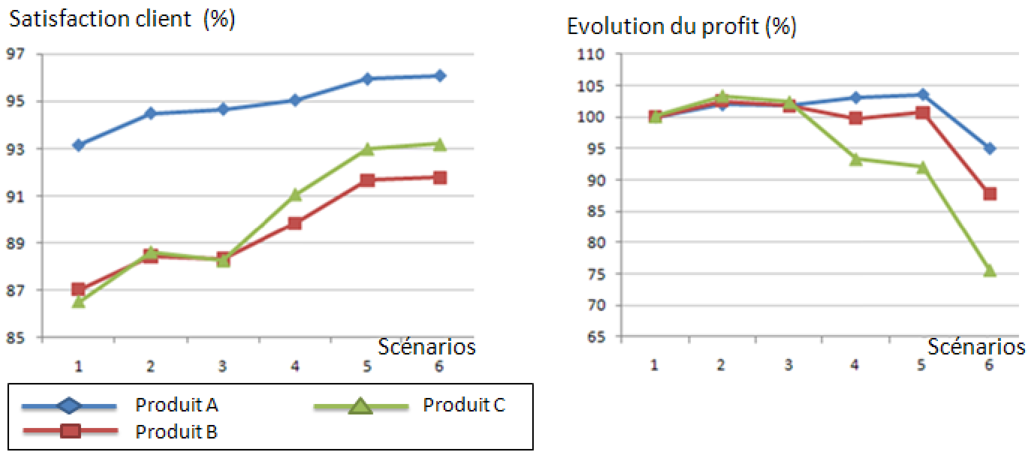
Tous les paramètres qui sont utilisés pour calculer le bénéfice (le prix de vente, le prix d'achat, le coût unitaire de livraison, le coût unitaire de stockage, le coût unitaire d'inventaire) dépendent des caractéristiques des produits et de la chaîne logistique. Nous définissons ces paramètres pour le modèle initial. Nous croyons que ces paramètres peuvent significativement influencer le bénéfice de la chaîne logistique. De là, changer ces paramètres est important afin d'évaluer les impacts des technologies RFID sur le bénéfice d'une chaîne logistique.

L'intégration des technologies RFID a deux principaux composants de coût; un coût unitaire d'étiquettes RFID et un coût fixe pour la mise en œuvre de la technologie (antennes, lecteurs manuels, lecteurs fixes, étagères intelligentes, etc). Les coûts variables des technologies RFID dépendent du coût unitaire d'étiquettes RFID et le nombre d'articles étiquetés. Dans notre modèle nous supposons que nous utilisons le même type d'étiquettes pour la RFID en boucle fermée et la RFID au niveau des palettes dans des Scénarios 2 et 3 et un autre type d'étiquette pour le marquage au niveau produit dans des Scénarios 4, 5 et 6. Les coûts unitaires des étiquettes RFID et les coûts fixes de technologies RFID ont été évalués selon le marché des RFID.

1.4.5.2 Résultats et analyses des simulations

La figure 1.5 montre la variation de satisfaction des clients et l'évolution des profits selon les six scénarios considérés. Les évolutions de la satisfaction de client et du profit sont présentées pour les produits A, B et C. Pour observer l'impact de chaque technologie RFID sur les profits, le scénario 1 étant pris comme référence, les autres scénarios sont évalués en pourcentage de celui-ci, du point de vue du profit (fig 1.5b).

La figure 1.5a présente la satisfaction de client pour les produits A, B et C. Ce graphique montre que la satisfaction de client pour les produits A, B et C augmente respectivement de 93.2 % à 96.1 %, de 87 % à 91.8 % et de 86.5 % à 93.2 %. Nous



(a) Satisfaction de client

(b) Evolution de profit

Figure 1.5: L'impact de l'intégration des technologies RFID : Produits A, B et C

remarquons que l'augmentation de satisfaction de client pour produit A est plus faible que pour les produits B et C intégration des technologies RFID. Cela signifie que dans le modèle initial le vendeur assure une haute satisfaction de client pour les produits A car ces types de produits sont les produits à forte valeur ajouté. Nous observons également qu'il existe deux augmentations remarquables de satisfaction de client pour tous les produits; remplacement des codes barres avec la technologie RFID en boucle fermée et par l'intégration des technologies RFID au niveau des produits. D'autre part, les satisfactions de client pour les scénarios 2 et 3 sont très proches. Cela signifie que l'intégration des RFID au niveau des palettes n'influence pas la satisfaction de client. De même, l'intégration d'étagères intelligentes n'est pas intéressant pour augmenter la satisfaction des clients.

Dans la figure 1.5b, nous observons que l'intégration de la RFID en boucle fermée augmente les profits pour tous les produits. Les profits obtenus par l'intégration de la RFID au niveau de palette sont très proches des profits obtenus par une RFID en boucle fermée pour tous les produits A, B et C. Donc, l'intégration des RFID au niveau des palettes n'est pas intéressant. Nous remarquons aussi que la technologie RFID intégrée au niveau de l'article est rentable pour les produits A et B, bien que cette technologie ne puisse pas compenser ses coûts pour un produit bon marché comme le produit C. Par la Figure 1.5b, nous notons que l'intégration d'une technologie RFID plus efficace (le Scénario 5) augmente les profits de chaque produit. Cependant, cette technologie n'est toujours pas rentable pour le produit C.

D'autre part, nous observons qu'en utilisant des étagères intelligentes, le Scénario 6 n'est pas rentable pour les produits A, B et C sur trois ans. Cependant, comme mentionné précédemment, cette technologie augmente la satisfaction de client par l'augmentation de la vente et la diminution des ventes perdues. À cause du haut coût des étagères intelligentes, le revenu supplémentaire ne compense pas les coûts technologiques.

1.4.5.3 Les analyses ROI

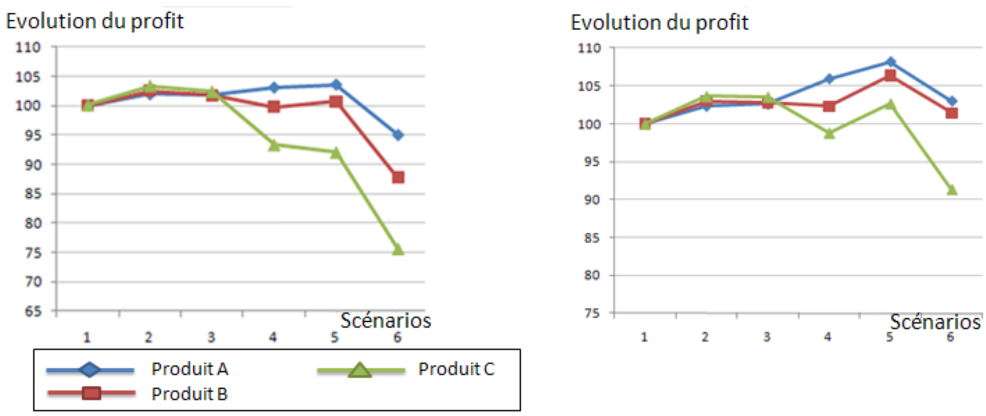
Les résultats de simulation de l'intégration des technologies RFID et réorganisation des chaînes par les RFID montrent que celles-ci peuvent augmenter la satisfaction de client et le profit des chaînes logistiques. Cependant, les mises en œuvre réelles exigent des investissements significatifs pour les sociétés parce que les systèmes RFID sont toujours plus chers que les systèmes d'identification actuels. Avant de décider l'intégration de ces technologies dans leurs systèmes, les sociétés doivent analyser les ROI pour évaluer leur rentabilité.

Dans cette étude nous utilisons notre approche de simulation pour évaluer dans combien de temps les technologies RFID peut compenser l'investissement significatif. Nous avons simulé chaque scénario séparément pour tous les produits pour des durées de 3 ans et 5 ans pour évaluer dans lequel des scénarios intégrant RFID des technologies deviennent rentables.

Nous analysons le ROI du remplacement des systèmes actuels par des technologies RFID. La figure 1.6 montre l'évolution du bénéfice pour les produits A, B, C pour différents horizons de temps et pour les 6 scénarios.

Dans la figure 1.6, nous observons que les applications RFID dans tous les scénarios sauf le dernier peuvent être rentables pour les produits A et B en trois ans. La mise en œuvre de la RFID dans le Scénario 6 (l'étagère intelligente) ne peut pas compenser les coûts de cette technologie et n'est pas rentable dans les trois ans pour tout les produits A, B, C tandis que cette technologie devient profitable pour des produits A et B dans les cinq ans. Il ne peut pas toujours compenser l'investissement pour les produits C, même en cinq ans.

Les analyses ROI montrent que chaque intégration des technologies RFID exige des périodes différentes par produit pour devenir rentable.



(a) L'évolution de profit dans 3 ans (b) L'évolution de profit dans 5 ans

Figure 1.6: Simulations de 3 et de 5 années : produits A, B et C

1.4.6 Réorganisation des chaînes logistiques par les technologies RFID

Les résultats de l'intégration des technologies RFID dans les chaînes logistiques montrent que, en améliorant l'exactitude, l'efficacité et la vitesse de processus, les technologies RFID augmentent la satisfaction de client, réduisent des coûts opérationnels comme le stockage et la distribution et augmentent des ventes en empêchant des ruptures de stock. Les chaînes logistiques sont en réalité conçues et organisées selon les propriétés des technologies actuelles. Les nouvelles fonctions des RFID peuvent aider à augmenter l'efficacité des chaînes logistiques en soutenant leur réorganisation. Nous considérons que la réingénierie des chaînes logistiques peut être faite à trois niveaux; opérationnel, tactique et stratégique.

La réorganisation des chaînes logistiques au niveau opérationnel consiste en la modification en décisions d'opérations qui sont prises par semaine ou quotidiennement. L'objectif de ce type de réorganisation est d'optimiser le fonctionnement de la chaîne logistique rapidement et aussi bon marché que possible par les modifications 'simples' des décisions opérationnelles. Nous proposons la réduction du point de commande pour la réorganisation de chaînes logistiques au niveau opérationnel.

La réorganisation au niveau tactique concerne les planifications des décisions à moyen terme dans les chaînes logistiques. L'objectif de ce type de réorganisation est d'améliorer le fonctionnement des chaînes logistiques avec des modifications de planification des décisions. Nous proposons les modifications en planification des décisions comme le contrôle des stocks et la stratégie d'approvisionnement.

La réorganisation au niveau stratégique correspond à la stratégie des chaînes logistiques ou des décisions de conception. La configuration des chaînes logistiques, l'affectation des ressources, la capacité de production, l'emplacement des stocks, les modes de transport sont les exemples principaux de telles décisions à long terme. Nous proposons les modifications au niveau stratégique telles que le contrôle des stocks et la stratégie d'approvisionnement.

La figure 1.7 représent les possibilités de la réorganisation des chaînes logistiques à trois niveaux. Dans cette partie nous allons focaliser sur la réorganisation au niveau stratégique.

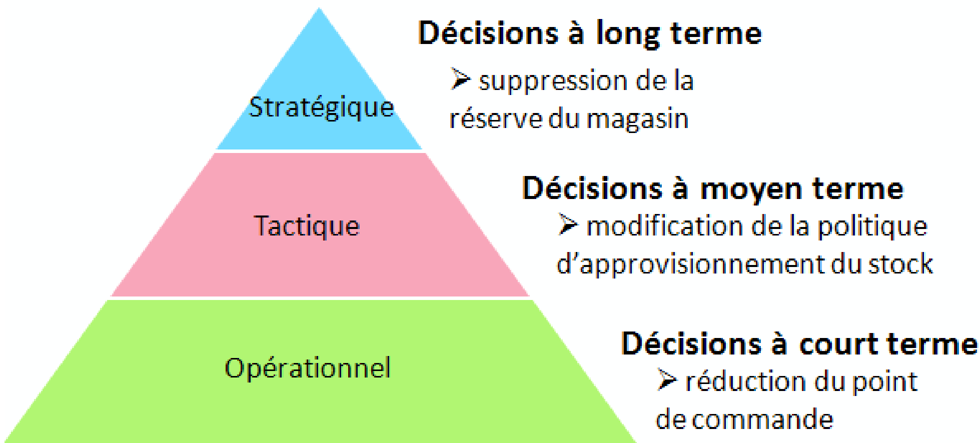


Figure 1.7: Réorganisation des chaînes logistiques à trois niveaux

1.4.6.1 La suppression de la réserve du magasin

Dans les chaînes logistiques, les niveaux de stock et les emplacements de stock sont très importants pour satisfaire la demande du client et augmenter le bénéfice total. Les résultats de l'intégration des technologies RFID dans les chaînes logistiques montrent que ces technologies fournissent une meilleure visibilité et une traçabilité sur les produits avec un stock moindre. La figure 1.8 montre l'évolution de niveau de stock dans la réserve du magasin et la satisfaction de client pour les produits A, B et C selon les simulations exécutées de l'intégration des technologies RFID dans les chaînes logistiques. Nous considérons les niveaux de stock du premier scénario comme référence (100 %) et nous analysons l'évolution du niveau de stock avec l'intégration de technologies RFID.

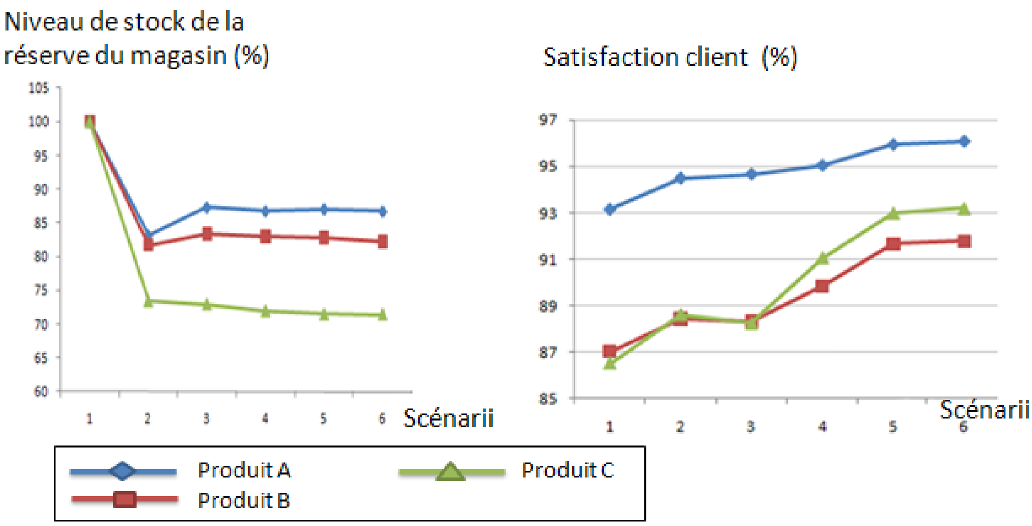
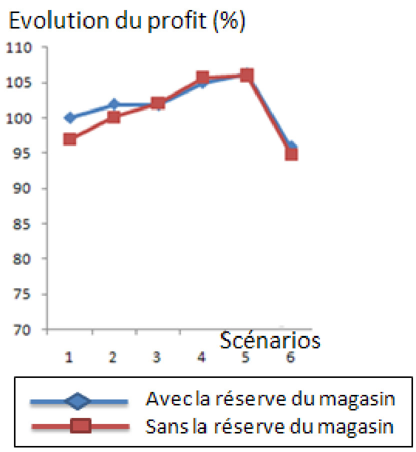


Figure 1.8: Niveaux de stock de la réserve de magasin et satisfaction de client: produits A, B and C

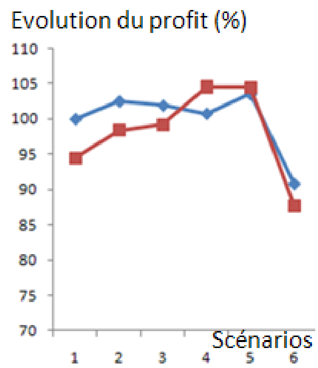
La figure 1.8 montre que les technologies RFID augmentent la satisfaction des clients en diminuent les niveaux de stock de produits A, B et C. Cela signifie que les RFID améliorent le fonctionnement de la chaîne logistique avec moins de stock dans la réserve du magasin. Moins de produits dans la réserve du magasin peut aboutir à plus d'espace de vente dans le magasin pour améliorer les ventes. Comme les technologies RFID fournissent les informations en temps réel sur les stocks et améliorent les processus de livraison, les chaînes logistiques pourraient être réorganisées en utilisant la réserve du magasin pour augmenter l'espace de vente dans les magasins.

Nous modélisons la chaîne logistique étudiée sans réserve du magasin. Les résultats présentées en figure 1.9 illustrent les bénéfices avec et sans réserve du magasin pour les produits A, B et C.

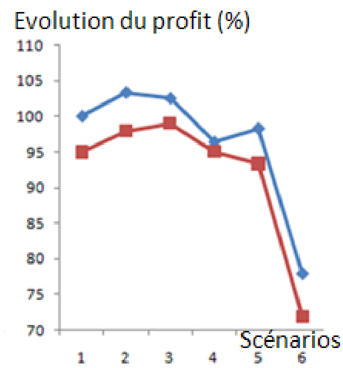
La figure 1.9b montre qu'en utilisant le stock en réserve du magasin comme l'espace de vente augmente le bénéfice de 1% pour le produit A et 4% pour le produit B par la technologie RFID au niveau de produit (Scénario 4). Cependant, la figure 1.9c montre que la suppression de la réserve du magasin n'est pas rentable pour le produit C mais elle augmente les profits des produits A et B. Il peut être



(a) Product A



(b) Product B



(c) Product C

Figure 1.9: Suppression de la réserve du magasin

noté que la réserve du magasin est nécessaire afin d'empêcher des ruptures de stock pour les produits avec une grande demande client.

1.4.7 Conclusion

Dans cette partie, nous avons simulé une chaîne logistique à trois niveaux dans laquelle l'inexactitude de stock arrive le long de la chaîne entière par différentes erreurs comme les vols, les produits mal placés ou les articles périmés ou abîmés

et les erreurs de livraison. Cette inexactitude peut affecter le fonctionnement de la chaîne logistique en augmentant les ruptures de stocks, les ventes perdues et les délais de livraison ou en diminuant la satisfaction de client.

Nous avons étudié différentes technologies RFID avec différents niveaux de marquage pour les produits divers qui ont des prix de vente différents et des demandes de clients différentes. Nous analysons les impacts de ces nouvelles technologies sur le fonctionnement d'une chaîne logistique actuelle et aussi sur la réorganisation des chaînes logistiques.

Notre simulation montre que l'intégration des technologies RFID en remplaçant simplement les technologies actuelles affecte la performance de la chaîne logistique et le bénéfice dans des proportions différentes. Les facteurs principaux qui influencent les impacts de technologies RFID sont :

- Propriétés des chaînes logistiques :
  - o Erreurs des chaînes logistiques,
  - o Niveaux des chaînes logistiques,
- Propriétés des technologies RFID :
  - o Niveau de marquage,
  - o Type de la technologie,
- Propriétés des produits:
  - o Prix des produits,
  - o Demande client,
- Durée d'utilisation,
- Méthode d'intégration (intégration simple ou réorganisation des chaînes logistiques).

Les résultats de simulation montrent aussi que les avantages des technologies RFID peuvent être améliorées par la réorganisation de chaînes logistiques par les nouvelles possibilités offertes par ces technologies. Cette amélioration dépend du niveau de réingénierie, des propriétés des technologies RFID, des caractéristiques des chaînes logistiques et des propriétés des produits.

Les résultats de simulations montrent que :

- la réorganisation des chaînes logistiques au niveau opérationnel peut augmenter les avantages des technologies RFID.
- la réorganisation des chaînes logistiques au niveau tactique en re-planifiant le contrôle des stocks peut significativement améliorer les avantages des technologies RFID comparées au remplacement simple des technologies actuelles.
- la réingénierie des chaînes logistiques au niveau tactique en changeant la politique d'approvisionnement pour les produits non fortement demandés peut significativement améliorer les avantages apportés par les technologies RFID.
- la réingénierie des chaînes logistiques au niveau stratégique en transformant l'espace de stockage dans la réserve du magasin en espace de vente dans le magasin avec les technologies RFID au niveau d'article:
  - o améliore les profits des chaînes logistiques pour les produits non fortement demandés,
  - o n'est pas rentable pour les produits fortement demandés.

Nous nous sommes aussi concentrés sur le ROI pour évaluer combien de temps les sociétés doivent attendre pour tirer profit après la mise en œuvre des technologies RFID. De nouveau, les résultats de simulation indiquent que le ROI des applications RFID diverses dépend de facteurs multiples, particulièrement le coût des technologies et des produits.

Les résultats de simulation du ROI montrent un seuil de rentabilité différent par produit, par type d'intégration et par durée d'utilisation.

L'originalité de cette étude est que nous comparons les impacts de plusieurs technologies RFID en les intégrant aux systèmes actuels et en reconstruisant des chaînes logistiques par les possibilités offertes par ces technologies.

Notre simulation peut être utilisée comme un outil d'aide à la décision pour les sociétés qui considèrent l'intégration de technologies RFID. En modifiant les paramètres de simulation, diverses chaînes logistiques peuvent être expérimentées.

Dans cette étude nous avons étudié une simple chaîne logistique à trois échelons. Cependant, les chaînes logistiques réelles sont habituellement plus complexes. Nous croyons qu'il serait approprié de poursuivre ce travail en intégrant des acteurs multiples à chaque niveau de la chaîne logistique pour observer l'interaction entre les acteurs. En outre, nous pensons qu'il serait intéressant de traiter des cas pratiques pour analyser des données plus réalistes pour notre approche de simulation, en particulier sur les coûts des technologies RFID.

1.5 Perspectives

Notre étude est une des premières recherches traitant de l'intégration de différentes technologies RFID dans une chaîne logistique complète. Nous avons développé des modèles analytiques et des modèles de simulation pour évaluer les impacts qualitatifs et quantitatifs des avantages de la RFID dans les chaînes logistiques. Les résultats obtenus dans ce travail mettent en évidence des perspectives intéressantes pour des études futures.

Notre étude de simulation se concentre sur une chaîne logistique à trois niveaux "simple". Il serait intéressant de poursuivre notre travail en intégrant de multiples acteurs à chaque niveau de la chaîne logistique pour évaluer les impacts des technologies RFID sur le flux d'information et de produit entre plusieurs acteurs.

Dans notre recherche, utilisant une approche par simulation, nous avons analysé les impacts de technologies RFID sur le fonctionnement et l'économie de la chaîne logistique en la réorganisant. Nous considérons les changements de la chaîne logistique aux niveaux opérationnel, tactique et stratégique, comme la réduction du point de commande, la planification du contrôle physique des stocks, le changement de la politique de recommande et la suppression de la réserve chez le détaillant. Dans cette étude, nous présentons nos premières réflexions et résultats sur la réingénierie des chaînes logistiques utilisant les nouvelles caractéristiques de technologies RFID. Cependant, la réingénierie peut être réalisée dans une vaste gamme. Nous croyons qu'il serait intéressant de considérer de nouvelles possibilités d'amélioration par réingénierie des chaînes logistiques; comme la suppression de niveaux d'intermédiaire de la chaîne logistique, ou le changement de processus de paiement. Nous utilisons des méthodes expérimentales pour optimiser la performance des chaînes logistiques afin d'améliorer les avantages des technologies RFID. Cependant, nous croyons que pour les futures études il serait intéressant de trouver la réorganisation optimale des chaînes logistiques en prenant en compte les technologies RFID.

Notre recherche est basée sur des problématiques réelles des chaînes logistiques et les caractéristiques du marché de RFID. Cependant, nous considérons des méthodes d'évaluation des impacts RFID sur la gestion des chaînes logistiques. Il sera souhaitable de les compléter avec des analyses pratiques en conduisant des mises en pratique d'intégration des technologies RFID dans des environnements réels pour comprendre leur faisabilité technique et la reconception du système afin de valider l'intégration des technologies RFID dans des systèmes complets. Les projets pilotes peuvent être appropriés pour tester ces technologies dans un environnement limité et simple, pour observer les difficultés et l'efficacité de leur intégration et observer les possibilités de réorganisation.

La plupart des travaux se sont concentrés sur les applications de gestion d'inventaire et sur la logistique. Cependant, nous croyons que les technologies RFID fournissent des avantages significatifs sur le cycle de vie total des produits depuis sa fabrication jusqu'au service après-vente. Les technologies RFID fournissent des avantages énormes pour des services d'après-vente comparés aux actuelles technologies d'identification. Par les technologies RFID, tout le processus de suivi de la vie d'un produit peut être enregistré. Ces informations pourraient aider à connaître les causes d'échecs potentiels en avance et ainsi soutenir des activités de maintenance. Les informations détaillées peuvent aussi aider à déterminer les parties du produit à recycler, ou à disposer. Les technologies RFID peuvent ainsi supporter le recyclage des produits et la traitement de produits dangereux. Il serait ainsi intéressant d'évaluer les impacts des technologies RFID sur la gestion des services après-vente et sur la gestion des processus de recyclage des produits.

Notre étude est la première sur les technologies RFID dans les chaînes logistiques qui a été effectuée dans le département "Science de la Fabrication et Logistique (SFL)" du Centre Microélectronique de Provence de l'Ecole Nationale Supérieure des Mines de Saint-Etienne. Nous croyons que cette étude fournit un contexte complet des chaînes logistiques qui permet d'analyser diverses chaînes logistiques en se concentrant sur leurs contraintes spécifiques. Ainsi, nous considérons que notre recherche est une étude clé qui peut être prolongée pour de nombreuses applications dans des chaînes logistiques diverses, comme le support de service après-vente et des applications de maintenance, dans des secteurs de luxe, textiles, etc.

Nos travaux ont été étendue par des projets de recherche dans SFL telles que l'intégration des technologies RFID dans des systèmes de santé, pour les activités de maintenance dans l'industrie aéronautique et le couplage RFID/GPS dans la distribution pour les produits à forte valeur ajoutée.

GENERAL INTRODUCTION

Problem statement

Supply chain is the group of all activities related directly or indirectly to create a product or service to satisfy a customer request [9]. Supply chains can consist of one or several actors such as suppliers, transporters, manufacturers, distributors, retailers and customers, etc. The objective of every supply chain is to maximize total supply chain profitability. Today's globalization conditions create a strong competition between companies. In order to maintain or strengthen their position in the market, companies have to ensure a high level customer satisfaction at the lowest possible cost and in a short time. However, reaching these goals is very hard. Main key factors to achieve these supply chain objectives are the value of information, inventory accuracy and physical inventory control.

- Information value:

  Companies must have the right product, in the right place at the right time to answer customer demands. This can be obtained through an efficient information flow between actors. The value of information is thus critical. Customer demand can be satisfied only with accurate and real time information. Different identification technologies are used to obtain accurate and actual information on inventories.

- Inventory accuracy:

  Most companies use information systems to have a good product visibility. However, over time, inventory information often distinguishes from the actual inventory information. This is called inventory inaccuracy and occurs because of several supply chain errors such as thefts, damages, frauds, misplacements, etc. It can thus reduce the service levels and profits of companies by increasing unexpected stock outs and thus causing the loss of potential sales.

- Physical inventory control:

  Inventory inaccuracy accumulates over time. To improve inventory accuracy, inventory records must be aligned by real inventory levels. This can be done by physical inventory counting. However, with the current identification technologies, this control is time consuming and may induce large operational costs.

In the last few years, Radio Frequency IDentification (RFID) technologies have drawn considerable interests as one of the possible solutions to overcome these supply chain problems. What is RFID? It is an automatic identification and data capture technology. An RFID system is composed of three elements: a tag formed by a chip connected with an antenna; a reader that emits radio signals and receives in return answers from tags, and a middleware that bridges RFID hardware and enterprise applications.

Why are RFID technologies considered as a possible solution? They have some advantages versus current identification technologies. Each RFID chip can contain a unique code that let companies to identify each product. RFID thus provides complete product visibility while the visibility is limited with bar coding technologies. Bar coding can only identify the types of products, since because of the limited identification capacity, the same code is given for all products of the same type. RFID tags can also store more data than bar codes. The main advantage of having a large memory capacity is that a complete visibility can be obtained independently of a back-end system. Furthermore, through RFID applications, it is possible to modify data during the tag life while bar code data cannot be changed once they are printed. These RFID read-write tags propose efficient applications to follow and record different characteristics of a product during its life cycle. Through radio waves, RFID technologies also provide a real-time contactless communication with numerous objects while, with bar coding technology, employees can read only one object at a time. They have to visualize each object and find the right line of sight to read the bar code. This type of reading requires time and human labor. Employees can easily make a mistake during the reading processes. On the other hand, RFID technologies automate identification processes. They accelerate reading processes, decrease employee errors and thus improve information accuracy. As a conclusion, the main advantages of RFID over bar coding technologies are:

Identification:

- Individual item identification rather than classes of items,
- More data storing capacity,
- Data modifying possibility,

Communication:

- Contactless,
- Multiple parallel reading capacity,
- No line of sight required.

Hence, through these advanced identification and communication characteristics, RFID can provide more accurate and real-time information. They can thus improve the value of information, decrease inventory inaccuracy and facilitate inventory counting.

RFID technologies are considered to provide numerous benefits in supply chains. What then is restraining companies to integrate these technologies? Companies hesitate to integrate RFID technologies in their systems because of economical and technical obstacles. The main reason is that integrating a new technology requires significant investments and also RFID are still more expensive than current identification technologies. Furthermore, metal and liquid environment can disturb reading performances of RFID technologies. Lack of international standards is another disadvantage. There are for instance differences between the frequency standards in Europe and the USA. Because of these obstacles, companies must conduct a rigorous analysis to compare the advantages and obstacles before deploying RFID technologies.

Research questions and research approach

In this thesis, we focus on RFID technology integration in supply chains. The literature on RFID applications in supply chains contains numerous qualitative and also quantitative studies. In surveying the literature, we observe that there are four main limitations. Most of the previous research considers RFID as a perfect technology which can eliminate all inaccuracy problems in supply chains. We also point out that these studies are limited to provide a complete analysis of the impacts of RFID technologies on supply chains performances and economical issues. Most of the studies analyze single-level supply chains and/or on a single-period time and/or for a single type of product. Most of the previous studies only develop analytical models. These models do not provide a dynamic analysis, so are not capable to fully estimate the impacts of real-time information obtained by RFID technologies. We also notice that most of the studies consider the integration of RFID technologies as replacing the current technologies with RFID technologies. However, actual supply chains have been designed during long years according to the characteristics and the working issues of current technologies such as bar codes.

In this thesis, we address these gaps. We consider that RFID technologies are not perfect and it is possible to use various RFID systems which propose different efficiencies through various investments. Through analytical models and simulations, we analyze how RFID technologies effect supply chains performances in terms of customer satisfaction, inventory levels, number of transportations, etc. Furthermore, we focus on economical analyses; particularly ROI (Return On Investment) analysis, to compare the benefits obtained by RFID technologies with the costs associated to the integration of these technologies. We also analyze how the benefits of RFID technologies can be improved in supply chains. We compare the impacts of integrating different RFID technologies to supply chains by just replacing current identification technologies and by re-engineering supply chains using the new possibilities provided by RFID technologies. Particularly, the questions tackled in this dissertation are:

- How can RFID technologies affect supply chains performances (customer satisfaction, inventory management, etc.)?

- Which factors can affect RFID performances?

- Which RFID technology is more efficient for different types of product?

- How long time is necessary before companies start to gain through RFID technology implementations?

- What is the critical cost of RFID technology (variable cost + fixed cost) for certain types of product?

- How do supply chain actors can gain the most out RFID technologies?

- What changes can RFID technologies carry out in the organization of systems to improve the performances and economics of supply chains?

Structure of the thesis

The remainder of this thesis is organized as follows.

A general overview of RFID technologies is presented in Chapter 2. We first present the general working process of these technologies. The challenges and the difficulties of RFID are also given to discuss the potential capacities and the limitations of RFID technologies in supply chains.

Chapter 3 proposes a literature review of the impact of RFID technologies in supply chains. The literature is classified in two main groups: content oriented papers and method oriented papers. Potential benefits of RFID technologies against inventory inaccuracy problems, the bullwhip effect and replenishment policies are the main subjects of the content oriented literature. Analytical modeling, simulations, case studies and experiments are the methods that are mainly used in the method oriented papers. We also present the studies that focus on ROI analysis to develop an economical analysis of RFID technologies.

Chapter 4 presents an analytical approach in order to evaluate the impact of RFID technologies on inventory management. We compare two Newsvendor models. The first model is developed to analyze a single period inventory system which contains several supply chain errors that cause stock outs and thus decrease the customer service level and sales. In the second model, RFID technologies which have different prices and performances are integrated in the first model to evaluate economical impacts of these technologies on inventory inaccuracy.

In Chapter 5, we present a simulation study of a three-level supply chain. This supply chain contains a manufacturer, a distribution center and a retailer. We consider three different products which have different prices and customer demands and which are replenished through a reorder point (s) and Economic Order Quantity (EOQ) policy. Inventory inaccuracy occurs in the chain because of different supply chain errors. This inaccuracy causes stock outs, poor customer satisfaction, long delivery times, etc. We consider various RFID technologies with different tagging levels for a single product or multiple products. We aim to first analyze the impacts of RFID technologies on supply chain performances and profits. We then compare the effects of re-engineering supply chains on the impacts of RFID technologies. We use discrete event simulation to analyze the impacts of RFID technologies on the supply chain performances and to get the ROI for each case.

Conclusion and perspectives are given in the last chapter. We aim to discuss the impact of RFID technologies on supply chains and develop an effective overview of the challenges and benefits of RFID integration in supply chains.

CHAPTER 2

SCIENTIFIC CONTEXT AND OVERVIEW OF RFID TECHNOLOGIES

RFID technologies may improve supply chain management by increasing the efficiency and speed of processes, improving information accuracy, reducing inventory losses, etc. This chapter presents a brief scientific context and a general overview of RFID including the working process, the challenges and the obstacles applying these technologies in supply chains. This chapter aims at providing the necessary understanding for the following chapters.

2.1 Introduction

A supply chain contains all material, information and financial flows and the relationships between the first suppliers to the end customers [29]. Figure 2.1 presents a supply chain model.

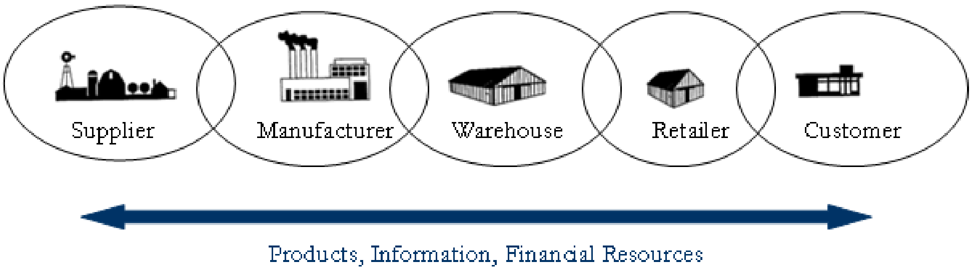


Figure 2.1: A model of supply chain

For successful supply chain management, supply chain decisions associated with the flows of information, products, services, financial resources must be made correctly. These decisions can be separated in three groups; strategic level, tactical level and operational level. Figure 2.2 represents these decisions.

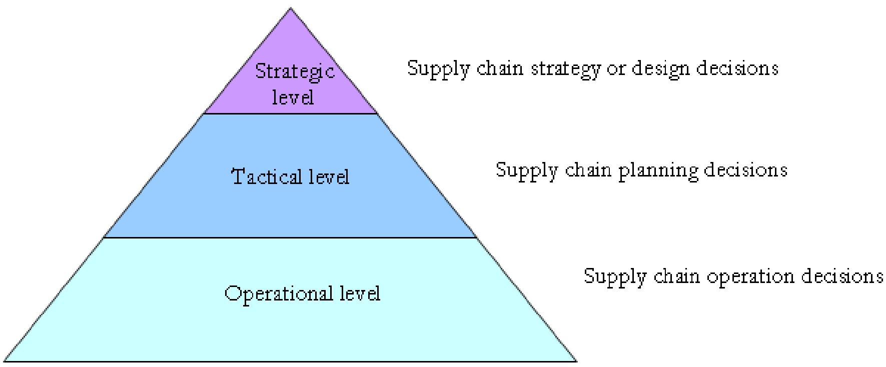


Figure 2.2: Supply chain decisions

- Strategic level: These are long-term supply chain design decisions taken in order to structure networks. Supply chain configuration, resource allocation, production capacity or inventory storage locations are typical decisions of this level

- Tactical level: Supply chain planning decisions exist at the tactical level. These decisions include medium-term operating policies taken in a configured supply chain to optimize performance.

- Operational level: This level contains short-term decisions made weekly or daily based on the current information. The objective of operational decisions is to optimize performance while taking into account uncertainty.

Strategic, tactical and operational supply chains decisions significantly impact the performance, profitability and success of supply chains. In order to be efficient in today's competitive market, supply chains have to carefully define their competitive strategies. Manufacturing planning, inventory management, transportation, handling systems, information systems are among the main supply chain management areas to develop a competitive strategy [29]. The response time, product availability, customer experience, order visibility and flexibility are some of the key factors to the supply chain performance. Figure 2.3 presents the key components of competitive strategy of supply chains.

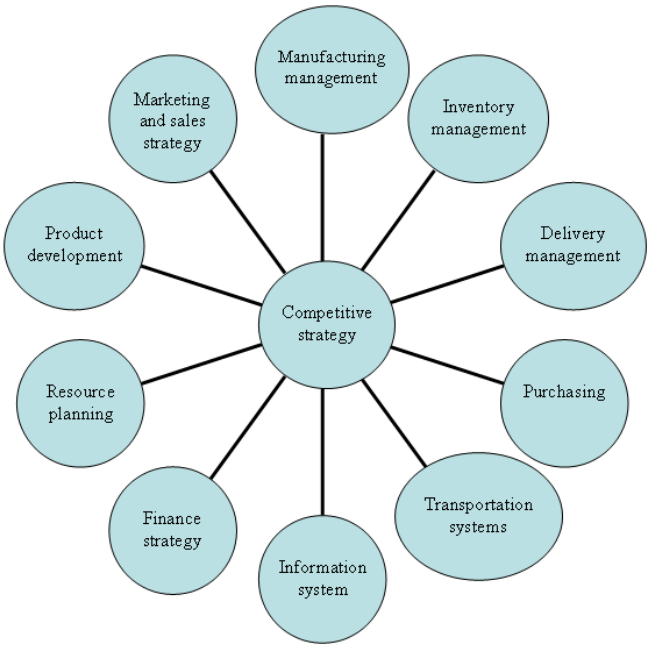


Figure 2.3: Key compenents of competitive strategy of supply chains

Radio Frequency IDentification (RFID) is an automatic identification (Auto-ID) technology. Bar codes, biometrics and voice identification are some other Auto-ID technologies. The specifity of RFID is that it uses radio waves to provide automatic identification and data capture.

Recent advances in microelectronics improve RFID technologies and increase their applications in supply chains. However, RFID is not a new technology. According to AIM [1], the first applications were created to differentiate friendly planes from enemy planes (IFF (Identification Friend or Foe) System, during the Second World War) [85].

In this chapter we present a general overview of RFID technologies with the working process, the challenges and the obstacles of their applications in supply chains. This chapter will help readers to understand the basics of these technologies and the following chapters.

The remaining of this chapter is organized as follows. Section 2.2 describes fundamentals of RFID technology in two parts; RFID systems and RFID basic concepts. A short comparison between RFID technologies and bar-coding systems is showed in section 2.3. Section 2.4 presents some RFID applications in industry. Conclusions are given in the last section of this chapter.

2.2 Fundamentals of RFID technology

2.2.1 RFID system

A basic RFID system contains three elements; a tag, a reader and a middleware. A tag is mainly formed by a microchip attached to an antenna. An RFID tag is read when it receives radio signals from the reader and sends data back to the reader. The middleware bridges the RFID hardware and enterprise applications. It filters the data and processes and interfaces this data with other software inventory and analysis systems [60].

An RFID system can be applied in order to identify an object, a pallet, a vehicle, etc. There are several types of RFID readers: fixed, mobile, portals, dock doors, etc. Therefore, various RFID systems can be obtained by combining different types of components at different levels. Figure 2.4 presents some possible RFID systems.

2.2.1.1 RFID tags

A “simple" RFID tag is composed of a microchip and an antenna. The antenna collects the electromagnetic waves coming from readers and broadcasts signals to

[1] The Association for Automatic Identification and Data Capture Technologies

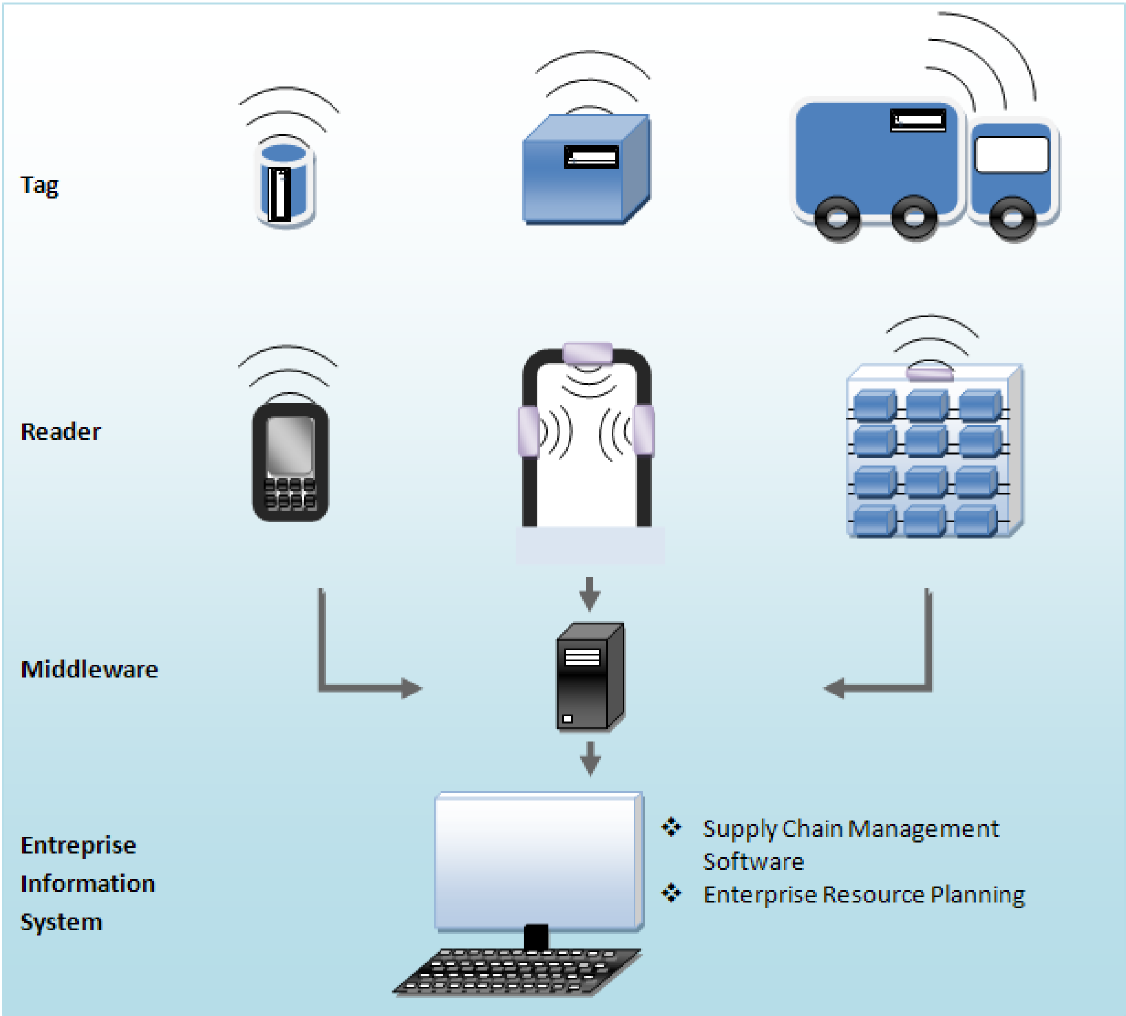


Figure 2.4: Some RFID systems

readers. The microchip is the memory part of the tag and contains information on the tagged objects. The chip can be read-only or read-write. Information cannot be changed in read-only chips. Information is thus static as in bar coding technology while information can be changed in read-write chips, and is thus dynamic. Read-write chips are more expensive than read-only chips and are used for high-value product items. Read-only chips are generally used for inexpensive objects [5].

There are different types of tags: active, passive, semi-active and semi-passive. Figure 2.5 shows several tags.

In this section, we focus on passive and active tags.

Figure 2.5: Some RFID tags

- Passive RFID tags: Passive tags do not have any internal power supply and use the power emitted from readers. They are typically in “sleep" mode until receiving signals from readers [141]. Their communication distance is related to the reader reading range. Passive tags have long operational life.

- Active RFID tags: Active tags have an internal power source to activate the chip and to emit the outgoing signal. Through their own power supply, active tags can answer the reader with a stronger signal, and thus can be read from long distances [52]. Their reading distance can be 30 meters approximatively [84]. In spite of their advanced capabilities, active tags are heavier and more expensive than passive tags. And their life durations are limited [141], related to their battery life (up to 10 years) [132].

RFID systems can be separated in two groups according to the tag type used: open loop and closed loop. In a closed loop, the same tags are used several times for the same processes. For example asset tracking is a typical example of a closed loop application. In this type of applications, tags are only read by one organization. Thus, the tag standard is not important. In an open loop, tags can only be used once for an object (item or case, etc.). Tagged objects must be readable by several actors of the supply chain such as manufacturers, distributors and retailers. Due to globalization, these actors can be in different continents. Thus, using international standards for these tags may be essential.

2.2.1.2 RFID readers

Readers can be classified according to the tags that they are reading. Readers for passive and active tags have different characteristics (see Table 2.1). Readers for passive tags must emit high power (up to 4W) in order to activate tags while readers for active tags need only about 15 mW power [141]. Readers for active tags can simultaneously read hundreds of tags in milliseconds, while in seconds readers for passive tags cannot read 100 tags.

	Power	Communication distance	Reading speed
Readers for passive tags	Max 4W	Some meters	$\prec$100 tags/second
Readers for active tags	10 - 20 mW	20 -100 meters	$\succ$100000 tags/second

Table 2.1: Some characteristics of readers for passive and active tags

A reader may have multiple antennas that are responsible for sending and receiving radio waves. The Antennas emit radio waves into their surroundings. The reader's performance depends on the antenna polarization (the direction of oscillation of radio waves) [84], and also the position and orientation between the tag and the reader antennas [46].

There are some technical difficulties for readers. If there is more than one reader working in a zone, the signals of a reader can damage the signals of another reader (signal collision). Another type of collision can occur while readers are reading several tags. To over-come these problems, the Auto-ID Center proposed to make readers that read tags at different times instead of simultaneously and to make tags that answer to the reader if their first digits match the digits of the desired tag [5].

2.2.1.3 RFID middleware

The RFID Middleware is an intermediate step between the RFID technology and the enterprise information system to evaluate the value of the technology. RFID technologies can provide massive amount of information. However, enterprises want to obtain only the necessary and accurate data. The role of the middleware is filtering the excess and unnecessary data, ensuring accuracy of this data, transforming it to useful information in order for companies to improve their management. The functions of the middleware are presented in Figure 2.6.

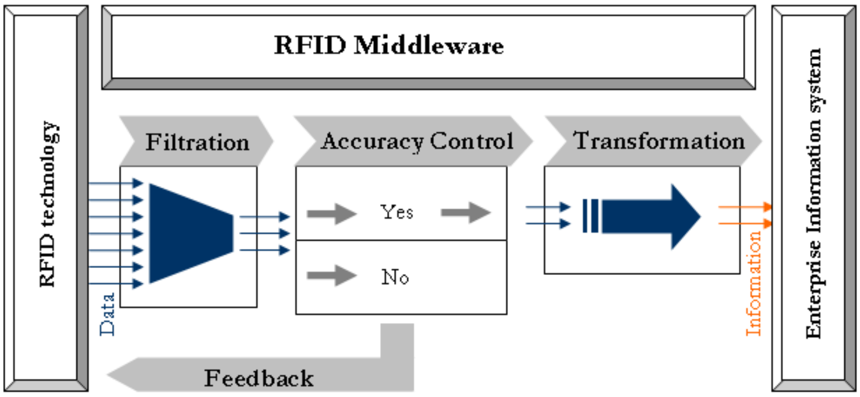


Figure 2.6: Functions of the RFID middleware

2.2.2 Basic RFID concepts

2.2.2.1 RFID frequencies

The range of the communication distance of RFID systems varies from just a few millimeters to 100 meters or more with active or passive tags. This range also depends on other factors, such as both the reader's power and the used frequency [5]. The information transfer rate and speed may also vary in a wide range and depend on various factors such as frequency used, communication distance as well as the active or passive tags that are used.

The frequency used in RFID technologies can be divided into four groups; low frequency (LF), high frequency (HF), ultra-high frequency (UHF) and microwave frequency.

- LF: This frequency uses 125 and 134.2 kHz. It allows a communication in a range of few centimeters. The data transfer rate is less than 1 Kbit per second [41]. It performs efficiently even in metal or liquid environment [84]. This frequency is typically used for access control or animal identification.

- HF: HF uses 13.56 MHz. This frequency can read RFID tags at a distance of about 1 m [19]. The data transfer rate is approximately 25 Kbits per second [41]. Metal and liquid environment do not disturb reading performances [84]. This frequency is used for applications related to access and security.

- UHF: This frequency uses 868 MHz in Europe and 915 MHz in the USA. The communication distance of UHF is up to 6 m. The data transfer rate is 100 bits per second [41]. However, it poorly performs in presence of metal and liquid [84]. This frequency is used for supply chain applications with pallet or case tagging, and also for asset management applications [19].

- Hyper F: This frequency enables an RFID reader to detect a tag at a distance of ten meters [19]. The data transfer rate can be up to 100 bits per second [148]. UHF waves are reflected by metals and refracted by liquids [154]. Therefore, the communication performance of UHW waves weakens in metals and liquids [84]. These problems can be solved by special packaging or by increasing tag and antenna position combinations.

Table 2.2 summarizes the characteristics of these frequencies.

	Frequency Band	Tag type	Reading distance	Reading speed	Performance with metal or liquid	Typical Applications
LF	125 and 134.2 kHz	Passive	50 cm	Slow $\prec$1 Kbit	Best	Animal tagging, access control, vehicle immobilizer
HF	13.56 MHz	Passive	1 m	Fast $\approx$ 25 Kbit	Better	Access control, payment, pharmaceutical
UHF	868 MHz (EU) 915 MHz (USA)	Passive Active	4-5 m	Very fast $\approx$ 100 Kbit	Worse	Supply chain, asset management, access control
Hyper F	2.45 GHz	Active	10 m	Very fast $\approx$ 100 Kbit	Worst	Security, access control, toll collection

Table 2.2: Some characteristics of RFID frequencies

2.2.2.2 RFID standards

In order to obtain the maximum benefits from RFID technologies, tags, readers and frequencies should function in harmony globally. Some organizations have been working to develop international standards to ensure this harmony. The creation and adoption of official standards can significantly increase RFID technology implementations [104]. There are two main RFID standards; data standards and technology standards.

Data standards

Data standards define the content of the memory of RFID tags, and also the storage format of this data. EPC (Electronic Product Code) is one of the main data standards. It has been developed by EPCGlobal in order to ensure the automatic and unique identification of objects in a unique way in the world. An EPC is a unique code for each product that can contain the information such as the manufacturer and type of the product, etc. There are different EPC formats; 64 bits, 96 bits or 128 bits. Figure 2.7 represents an EPC-96 bits.

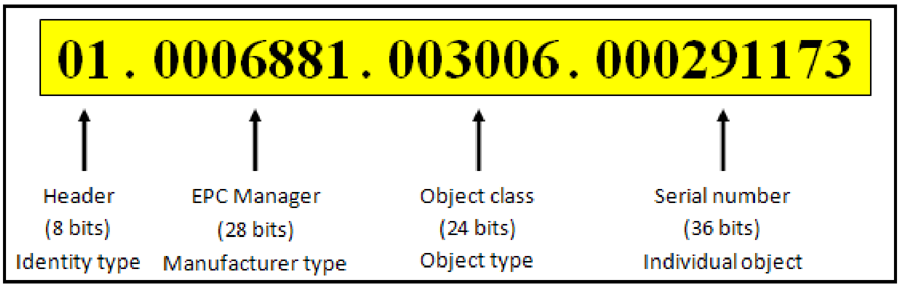


Figure 2.7: An EPC-96 bits

The first part (header) can define the overall length, identity type and the EPC scheme structure. The second part (EPC Manager) can define the manufacturer. The third part (Object Class) can identify the object type. And the last part of the EPC can identify individual object [71]. An EPC of 96 bits can identify more than 268 million manufacturers, more than 16 million types of objects and almost 69 billion articles for each manufacturer [17].

Technology standards

Technology standards define communication protocols between the tag and the reader. One of the main technology standard organizations is called the International Organization for Standardization (ISO). It has a partnership with international organizations, governments, industries, and business and consumer representatives to provide international standards in about 148 countries.

Several standards have been developed by ISO. Table 2.3 presents some ISO standards. These standards are ISO 11785 for 125 KHz (LF), ISO 15693 for 13.56MHz (HF), ISO 18000-6 for 860-930MHz (UHF), ISO 15693 for passive, read-write tags which work at HF [94], ISO 14443 (for contactless systems), and ISO 18000 (to specify the air interface for a variety of RFID applications) [150].

ISO standards	Scope
ISO 11785	LF applications
ISO 15693	HF applications
ISO 18000-6	UHF applications
ISO 15693	Passive, read-write tags which work at HF
ISO 14443	Contactless systems
ISO 18000	Air interface for RFID applications

Table 2.3: Some ISO standards

2.3 RFID versus bar codes

In this section we compare RFID technologies with bar coding technologies. We first present basics of bar coding technologies. We then present the main advantages of RFID technologies over bar codes and reciprocally bar codes advantages over RFID. Table 2.4 presents a comparison between RFID and bar coding technologies.

	Bar-coding technologies	RFID technologies
Reading	- Line-of-sight - One by one	- Contactless, line-of-sight not required - Multiple tags simultaneously
Identification	- Classes of products - Data storage is limited - Data is static (cannot be changed)	- Individual object (unique) - Too much data can be stored - Data is dynamic (can be updated)
Environment	- Bar codes can be damaged by physical and chemical conditions	- RFID frequency can be disturbed by metal and liquid environment
Cost	- Cheap	- Expensive
Political and social issues	- Deeply entrenched - No privacy issue	- Lack of standards - Privacy and security issues

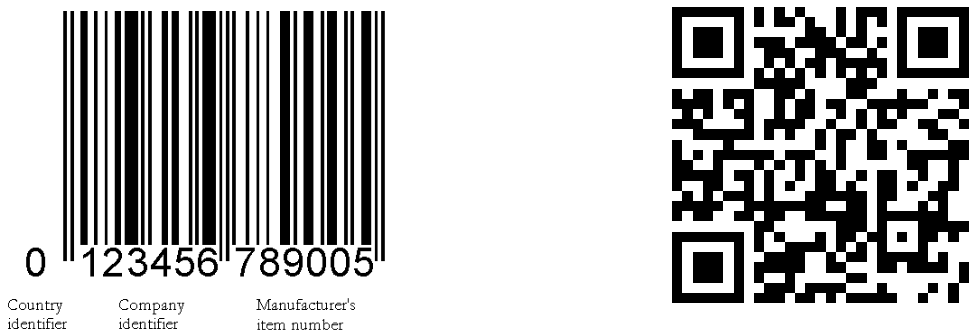
Table 2.4: Comparison between RFID and bar coding technologies

2.3.1 Bar coding technology

The most common auto-ID technology is bar coding. The total volume of bar code systems in Europe at the beginning of the 1990s was indicated around 3 billion

DM [46]. There are three components of a barcode system; a barcode, a scanner and a computer. The barcode is the data encoded as an image of black lines on a white background. When the barcode is scanned, the image is transformed to a digital data and transferred in the computer.

The most popular bar code is EAN code (European Articles Number) formed by 13 digits that identify the country and company, manufacturing item number and a check digit. Figure 2.8a presents a simple barcode and its EAN coding.



(a) A barcode and its EAN coding

(b) A matrix barcode

Figure 2.8: Different types of bar codes

There are different types of bar codes; linear bar codes, matrix (2D) bar codes, etc. A matrix code, also known as a 2D barcode, represents information in a two-dimensional format. It functions similarly to a linear (1-dimensional) barcode, but has more data representation capability. Figure 2.8b presents a matrix barcode.

2.3.2 Advantages of RFID over bar codes

RFID technologies have some advantages over bar coding technologies. We focus these advantages in three groups; reading, identification and physical advantages.

2.3.2.1 Reading advantages

Contrary to bar codes, RFID technologies do not require physical contact or line of sight between tags and readers to communicate. Multiple RFID tags can be read contactless and at one time. This means that there is no time spent in finding and touching each object one by one to read tags. These properties thus facilitate and speed up reading operations than with bar coding technologies.

RFID tags can be read farther than bar coding technology. Bar codes can be read by readers within a few centimeters distance while RFID active tags can be read at distances up to about 100 meters. The long reading range of RFID technologies improves the supply chain visibility more than with bar coding technologies.

Actual RFID applications show that RFID technologies are more accurate than bar codes. In RFID technologies, reading operations are automated. Hence, there are less errors due to human labor with RFID than with bar coding technologies. However, the accuracy of RFID technologies depends on several environment factors. According to the company requirements, the accuracy of RFID technologies can be improved with better tags, readers and antennas [84].

2.3.2.2 Identification advantages

Because of poor identification capacity, bar codes can only identify classes of objects while item level RFID can identify each product. RFID applications at item level thus provide a better supply chain traceability and visibility than bar codes.

RFID tags can store more data than bar codes. The main advantage of having a large memory capacity is that a complete visibility can be obtained independently of a back-end system.

Through RFID read-write tag applications, it is possible to modify data during the tag life while bar code data cannot be changed once they are printed. These RFID read-write tags propose efficient applications to follow and record environmental data such as temperature, pressure, etc. This is important for tag recycling to reuse the same tag for new objects, particularly in closed loop applications.

2.3.2.3 Physical advantages

RFID tags have some physical advantages over bar codes. RFID tags resist to environment conditions better than bar codes. Bar codes can be damaged easily with humidity or dirty environment while passive RFID tags can performs in difficult environmental conditions such as heat, humidity, vibration, shock, etc. RFID tags thus have longer life time than bar codes. The tag life depends on environmental conditions and tag types; it is up to 10 years for active tags and more than 10 years for passive tags.

2.3.3 Advantages of bar codes over RFID

Bar codes have been used in supply chains for over 30 years. They have some economical and social advantages over RFID technologies.

2.3.3.1 Economical issues

Bar codes are cheaper than RFID technologies. The current costs of RFID tags are still above 5 cent ($)/tag while a bar code costs under one cent ($) [19]. Furthermore, the costs of equipment and integration of RFID technologies are significantly larger than the costs of bar coding technologies. Companies would need significant investments for replacing the existing bar coding technologies with RFID technologies.

2.3.3.2 Deeply entrenched technology: No social issues

Bar coding technologies are deeply installed in all local and international supply chains. This technology is well known by all employees and customers. Bar codes are visible, and there is thus no privacy issues for bar codes while RFID technologies cause social hesitation due to their privacy, security and international compatibility issues.

2.4 RFID applications in industry

RFID technologies provide numerous advantages compared to current identification technologies. They have gained significant interest from supply chain industries and academics in recent years. But, they still have some technical and cost issue to replace current identification technologies. However, in recent years, there have been significant advancements in RFID technologies, important cost reduction and progress in standardization studies. For example, the components of this technology are becoming smaller and smaller, less expensive and more effective [98]. Thus, applications of RFID in supply chain have increased. Bagchi *et al.* [8] reported the prediction of RFID growth from $1 billion in 2003 to $4 billion in 2008 to $20 billion in 2013. Furthermore, the increase of RFID implementation also improves RFID technology and standards, as well as decreases its cost. Figure 2.9 represents the price-volume sensitivity envelop for RFID [59]. The tag prices are represented for special product families such as military objects, books, drugs, high priced retail goods (Retail HP) and low price retail goods (Retail LP), etc.

Current applications of RFID focus on inventory management, logistics and transportation, assembly and manufacturing, asset tracking and object location, environment sensors, etc [52]. Some sectors have more opportunity to gain from various RFID applications, such as retail, healthcare, textile, automotive and luxury good industries [94].

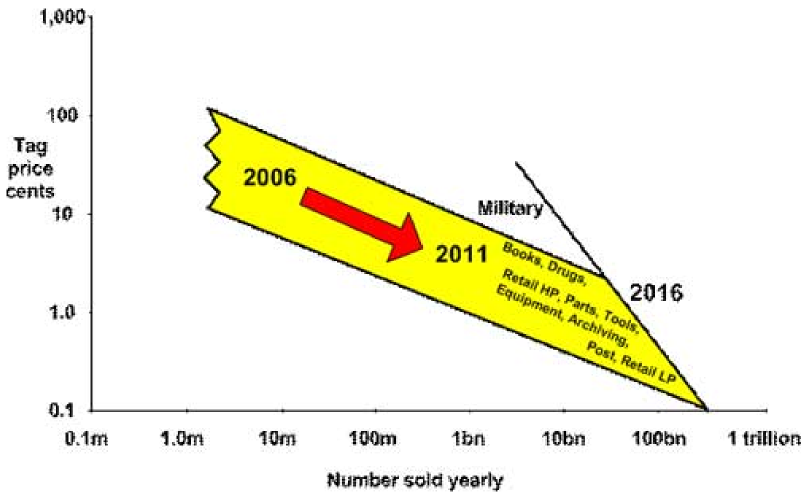


Figure 2.9: The price-volume sensitivity envelop for RFID [59]

RFID technologies offer several contributions to supply chain through their advanced properties such as unique identification of products, easiness of communication and real time information (Saygin *et al.* [125], Michael and McCathie [101]). Thus, RFID can improve the traceability of products and the visibility throughout the entire supply chain, and also can enhance the reliability and speed uf tracking, shipping, checkout and counting processes, which leads to improved inventory flows and more accurate information (Chow *et al.*, Tajima). Leung *et al.* [93] present the benefits of RFID in three main groups; revenue, operating margin, capital efficiency.

The benefits of RFID technologies can vary according to tagging level; such as pallet, case, and item-level tagging. Alexander *et al.* [4] present the opportunities and benefits realized across the supply chain due to different levels of tagging in Figure 2.10.

RFID implementations improve current systems. These technologies can also lead to large gains in the overall supply chain effectiveness by reorganizing processes (McFarlane *et al.* [99], Agarwal [1], Langer *et al.* [86]). Bottani and Rizzi [16] conclude that reengineering models highlight possible benefits gained through RFID for all processes of distribution centers and retailers.

There are not many real supply chain applications yet. Enterprises generally conduct pilot projects to validate this technology in a limited environment. According to Chappell *et al.* [26] the purposes of pilots are to validate the technology for reduced-scale and to prepare the systems for full-scale implementation and integration.

The US Department of Defense, Wal-Mart, the Food & Drug Administration,

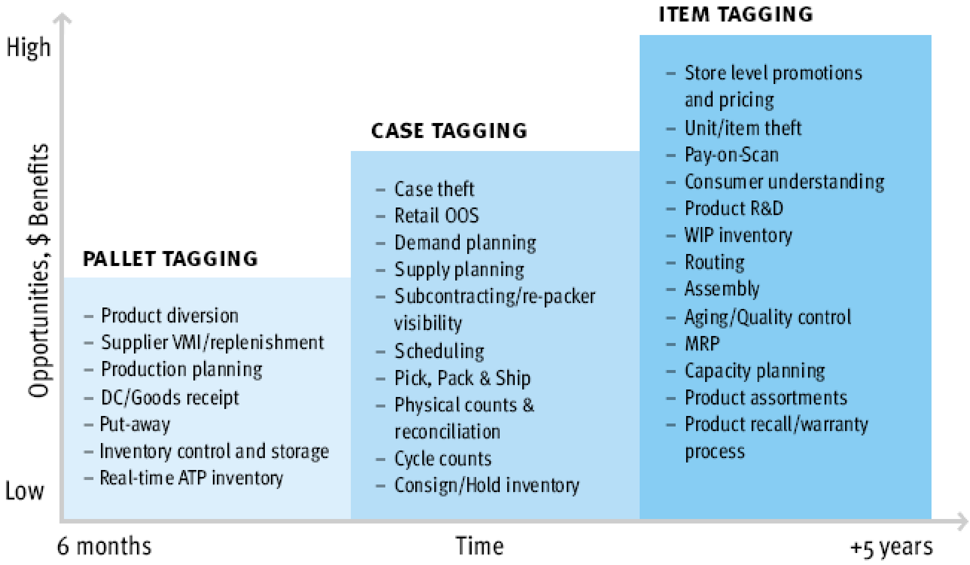


Figure 2.10: RFID benefits obtained at different levels of tagging [4]

Mark and Spencer, Tesco, Gillette are some of the pioneers of RFID technologies users [8]. In 2005, Wal-Mart asked their top 100 suppliers to tag all their pallets and cases [147], [94], [154]. Through this innovative attempt, Wal-Mart provided a considerable acceleration to RFID implementations in supply chains. According to the analysis of the University of Arkansas, Wal-Mart succeeded in adopting the RFID technology and reduced out-of-stocks by 16% [16]. Roberti [115] shows that out-of-stock items with RFID were replenished three times faster than items using standard barcode technology. He also concludes that Wal-Mart experienced a 10% reduction in manual orders resulting in a reduction of excess inventory. Mark & Spencer is also employing RFID technologies in its refrigerated food supply chain. Wamba *et al.* [145] report that they are tracking 3.5 million reusable trays, dollies and cages using RFID, and about 70% of the products are perishable in this chain. Wilding and Delgado [152] show that, through RFID technologies, Mark & Spencer gained 83% reduction in reading time for each tagged dolly, 15% reduction in shrinkage, a reduction in lead time and also an improvement of inventory management.

2.5 Conclusion

In this chapter we present a general overview of RFID technologies in three parts; basics of RFID technologies, a comparison with bar codes and RFID applications in industries. We analyze RFID technologies in supply chains to provide a better understanding for the next chapters.

RFID technologies provide numerous advantages compared to the current identification technologies. But, they have still some technical and cost issues to be able to replace current identification technologies. However, applications of RFID in supply chain have increased in recent years through significant technological advancement in RFID technologies, important reduction of the prices and the progress in the standardization studies.

In the next chapter, we will analyze the literature of the economical and physical impacts of RFID technologies on supply chains. We discuss the literature to develop an effective overview of the challenges and benefits related to integrating RFID in supply chains.

CHAPTER 3

LITERATURE REVIEW OF RFID APPLICATIONS IN SUPPLY CHAINS

This chapter gives a state-of-the-art survey on RFID technology deployments in supply chains to develop an effective overview of the challenges and benefits related to integrating RFID in supply chains. By surveying the literature, we observe that the main areas that RFID can deal with and thus can improve the efficiency of systems are inventory inaccuracy, the bullwhip effect and replenishment policies. Analytical models, simulations, case studies and experiments are the main approaches that were developed to analyze the impact of RFID technologies on supply chain management.

Part of this chapter [123] was submitted for publication in the *International Journal of Production Economics*.

3.1 Introduction

This chapter reviews the literature of the economic and physical impacts of RFID technologies on supply chains. We aim to discuss the impact of RFID technologies on supply chains to develop an effective overview of the challenges and benefits related to integrating RFID in supply chains.

We collect the literature from book chapters, dissertations, working papers, technical reports, conference papers and also from journals on supply chain management, operations research, information systems and production economics. Each article is reviewed through statements, critical analyses and also discussions on the impacts of RFID technologies on supply chain management.

By surveying the literature, we observe that the main areas that RFID can deal with are inventory inaccuracy, the bullwhip effect and replenishment policies. Analytical models, simulations, case studies and experiments are the main approaches that were developed to analyze the impact of RFID technologies on supply chain management. Hence, we classify the publications according to two criteria: content oriented and methodology oriented. Figure 3.1 illustrates our classification method.

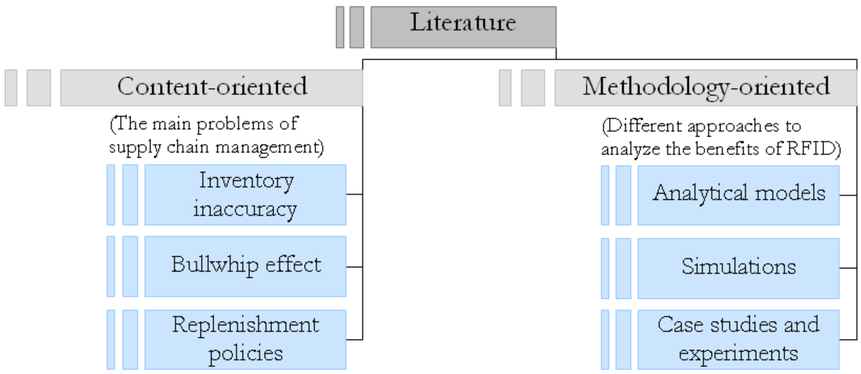


Figure 3.1: Methods to classify publications

The remainder of this chapter is organized as follows. We present a general overview of literature on RFID technologies in supply chains in Section 2. Section 3 surveys content oriented publications, which deal with the main problems of supply chain management that can be improved by RFID technologies. The methodology oriented papers are discussed in Section 4. Section 5 reviews ROI analyses. In the last section, some concluding remarks and research perspectives are presented.

3.2 General overview of literature on RFID technologies in supply chains

Current studies of RFID in supply chains focus on inventory management, logistics and transportation, assembly and manufacturing, asset tracking and object location, environment sensors, etc [52]. Some sectors have more opportunity to gain from RFID applications, such as retail, healthcare, textile, automotive and luxury good industries [94]. Automobile industry, particularly in the assembly process, is one of the most popular RFID applications in USA and Canada [60]. Additionally, RFID technologies can improve the efficiency and effectiveness of healthcare operators in numerous ways, such as smarter physical flows (patients, beds, etc.), accuracy of information flows (patient's history, treatment records, etc.) and better inventory management (medicine linens, beds, etc.) [11].

Most of the existing studies were published in the last few years. We can separate these publications in two groups; practical papers (white papers, technical reports) and academic papers. In these studies, several subjects are analyzed through different approaches. Table 3.1 presents a general classification of papers according to the most used approaches and the main topics of the publications on RFID applications in supply chains.

Publications	Most used Approaches	Main Topics
Practical papers	Pilot projects	Inventory management
	Case studies	Logistics and Transportation
	ROI analyzes	Assembly and Manufacturing
		Asset tracking and Object location
		Environment sensors
Academic papers	Analytical approach	Inventory inaccuracy
	Simulation approach	Bullwhip effect
	Case studies	Replenishment policies
	ROI analyses	
	Literature review	

Table 3.1: Types of publications

Practical papers generally deal with pilot projects, case studies and ROI analyses of RFID implementations in supply chains. Companies deploy pilot projects to test this new technology in a small and simple environment to observe the difficulties and the efficiencies of its integration, to analyze the associated costs and profits and to facilitate the complete integration in the whole company if they decide to implement it. In a white paper by IBM about improving product availability at the Retail Shelf by using Auto-ID technologies, Alexander *et al.* [3] focus on the difficulties for enterprises to adopt RFID systems through the consumer retail value chain. They illustrate the impact of the Auto-ID system on specific problems faced by companies in the consumer retail value chain. Similar papers on the value of RFID in supply chains were published by Kambil and Brooks [73], Chappell *et al.* [26] [25], Tellkamp [135] and Lee *et al.* [90]. The white paper of Bitkom [15] presents an overview of numerous applications of RFID systems in Germany. This paper focuses on four case studies such as logistics processes at Hewlett-Packard GmbH, flexible automotive processes at BMW, mobile maintenance solution in airport industry at Fraport AG, and logistics processes in the retail supply chain at Metro Group. One of the results of these case studies showed that, in Metro Group, RFID technology decreased losses during transit by 11-14%, improved the availability of items in stores by about 14%, and reduced costs in merchandise distribution centers by 11%.

Recently, numerous academic papers deal with potential benefits of RFID in supply chains. Authors were mostly interested in supply chain problems that RFID technologies have the possibility to solve. Inventory inaccuracy (Kang and Gershwin [74], Atali *et al.* [6], Fleisch and Tellkamp [48]...), bullwhip effect (Joshi [72], Lee *et al.* [91], Fleisch and Tellkamp [48]...), and choosing the optimal replenishment policy (Kok and Shang [34], Lee *et al.* [91]...) are some of these problems. In order to analyze the impact of RFID on supply chain systems, four main approaches are investigated: analytical approach (Lee and Ozer [88], Rekik *et al.* [113]...), simulation approach (Brown *et al.* [20], Leung [93]...), case studies and experiments (Lefebvre *et al.* [92], Wamba *et al.* [145], Bottani and Rizzi [16]...). Generally all of them are followed by a Return on Investment (ROI) study to quantify the economic impact of RFID in supply chains (Lee *et al.* [90], Kang and Koh [75]...).

In the literature, different state-of-the-art on RFID technologies on supply chains are presented. Gunesekaran and Ngai [57] review the literature on Build-to-Order Supply Chain (BOSC) management. They aim to highlight RFID technology as one of the important information technologies for BOSC that increases efficiency and accuracy. Extending this study, Ngai *et al.* [104] review and classify the literature on RFID technologies that was published between 1995 and 2005. They analyze qualitative and quantitative development of the knowledge in this area. This study includes a content-oriented classification of the RFID literature. Németh *et al.* [105] present a state-of-the-art on RFID systems and the challenges and possibilities of the integration to supply chains. This paper gives only an overview on current development of RFID technology and processes. Chao *et al.* [24] review the literature on trends and forecast of RFID technologies from 1991 to 2005 by a historical review method and bibliometric analyses. They focus on the RFID innovation, deployment by enterprises and market diffusion in supply chain management. This survey classifies the RFID literature according to several criteria, such as publication country, institution, year, document type, language, subject category, etc. However, we observe the lack of critical analyses on these publications. Recently, Delaunay *et al.* [37] present a survey on the causes of inventory inaccuracy in supply chain management, and give a perspective to future studies on the impact of RFID technologies on inventory inaccuracy in supply chains. Dolgui and Proth [40] also present a literature review on RFID technology in supply chain. They focus on the advantages of RFID technologies in inventory management. They also analyze some problems and present perspectives dealing with privacy and authentication properties of RFID technologies. The authors give a general point-of-view on RFID applications by analyzing selected publications in the literature.

In this chapter, we present a state of the art on the impacts of RFID deployments in supply chains. Contrarily to other relevant surveys, we present a complete review of the literature through statements and critical analyses of related publications and also by giving significant discussions on the impacts of RFID technologies on supply chain management.

3.3 Potential benefits of RFID in supply chains

RFID technologies offer several contributions to supply chain through their advanced properties such as unique identification of products, easiness of communication and real time information ([101], [125]). The progress through RFID can be observed in different types of supply chains such as warehouse management, transportation management, production scheduling, order management, inventory management and asset management systems [11].

RFID can improve the traceability of products and the visibility throughout the entire supply chain, and also can enhance the reliability and speed of operational processes such as tracking, shipping, checkout and counting processes, which leads to improved inventory flows and more accurate information ([30], [132]). Companies integrate and store the more accurate data obtained through RFID technologies in their information technology systems for better supply chain planning and management [151]. There is thus a strong link between IT applications and RFID technologies.

Through these numerous benefits, RFID technologies can provide cost reduction, increased revenue, process improvement, higher service quality, etc. Banks *et al.* [11] show a list of general quantitative and qualitative key factors for RFID implementations. Table 3.2 presents key RFID drivers proposed by Banks *et al.* [11].

Quantitative	Qualitative
Cost reduction: * Reduce labor force required * Reduce quality issues * Decrease shrinkage * Reduce labor time required * Increase asset proctivity * Increase supply chain visibility * Provide location visibility	Service improvement: * Customer goodwill * Quality of service * Quality of work environment * Corporate image * Market position * Market share
Revenue increase: * Increase revenue-capture rate	Customer service increase: * Increase repeat customers

Table 3.2: Key RFID Benefits

However, as mentioned before, the objective of RFID implementation is not just to improve current systems. Reorganizing processes using this new technology can also lead to large gains in the overall supply chain effectiveness ([1], [86], [99]). Bottani and Rizzi [16] indicate that reengineering models increase possible benefits gained through RFID for all processes of distribution centers and retailers. Dutta *et al.* [42] conclude that RFID integration through new business architectures provides more benefits than technology integration in current business processes.

In this section, we present potentials benefits of RFID technologies in supply chains. We are particularly interested in three main difficulties of supply chain management that can be improved through RFID; inventory inaccuracy, the bull-whip effect and choosing the right replenishment policies.

3.3.1 Inventory inaccuracy problem

Inaccuracy problems in inventory management are important in supply chain management. Although many companies have automated their inventory management using information systems, inventory levels in information systems and the real physical inventory levels often do not match [74]. The difference between these inventory levels is called inaccuracy and can deeply affect the performance of firms. DeHoratius and Raman [36] report that 65% of the inventory records in retail stores were inaccurate. The result was obtained in a case study, by examining about 370,000 inventory records from 37 stores of an important retailer (Gamma). Raman *et al.* [110] report that such inaccuracies could reduce the profit of retailers by 10% due to higher inventory cost and lost sales.

Since the earliest paper of Iglehart and Morey [70], there are numerous papers in the literature that have considered the impact of inventory inaccuracy and its causes.

	Transaction errors	Shipment errors	Delivery errors	Scanning errors	Incorrect identification	Shrinkage errors	Theft	Unavailable for sale	Vendor fraud	Administrative errors	Inaccessible inventory	Misplacement	Supply errors
Iglehart and Morey[70]	*												
Bullard and Resnik[22]						*	*						
Krajewski *et al.*[83]	*		*										
Brooks *et al.*[18]	*		*	*		*	*						
Yano and Lee[155]													*
Raman[110]	*	*		*									
Lightburn[95]						*		*					
Alexander *et al.*[3][4]	*	*	*	*		*	*	*					*
Kang and Koh [75]						*							
Chappell *et al.* [26][25]											*	*	
Kok and Shang [34]	*												
DeHoratius and Raman [36]	*	*		*							*	*	
Wong and McFarlane[153]	*		*			*	*				*	*	
Tellkamp *et al.*[134]	*			*		*	*		*	*			
Lee *et al.*[91]	*				*	*					*		
Kang and Gershwin[74]	*				*	*	*						
Fleisch and Tellkamp[48]	*		*			*	*	*			*	*	
Kleijnen and Van Der Vorst[82]						*							
Sahin [116]	*					*	*	*			*	*	
Lee and Ozer[88]	*		*	*		*	*	*	*		*	*	
Bensoussan *et al.*[14]						*		*					*
Camdereli and Swaminathan[23]											*	*	
Atali *et al.*[6]	*			*		*	*	*			*	*	
De Kok *et al.*[33]	*					*					*	*	
Ketzenberg and Ferguson[77]						*		*					
Rekik *et al.* [111][113][114][112]	*	*		*		*	*	*		*	*	*	*
Tellkamp[135]	*	*	*	*		*	*	*	*	*	*	*	
Basinger[13]	*	*		*	*	*	*	*	*		*	*	
Doerr *et al.*[39]	*	*				*							
Kim *et al.*[81]						*							
Tajima[132]						*	*	*					
Leung *et al.*[93]	*		*		*	*	*	*			*		
Delaunay *et al.* [37]	*					*						*	*
Uçkun *et al.* [139] [138]	*					*						*	
Sarac *et al.* [119] [121]						*	*	*				*	

Table 3.3: Survey on the causes of inventory inaccuracy

Table 3.3 represents a survey on the different causes of inventory inaccuracy. We can classify them in four groups; transaction errors, shrinkage errors, inaccessible inventory and supply errors.

Transaction errors were introduced in inventory management by Iglehart and Morey [70]. Several authors followed this study (Krajewski *et al.* [83], Brooks *et al.* [18]...). Transaction errors include shipment errors, delivery errors, scanning errors

[109] and also incorrect identification of items [91]. Shipping errors can be very expensive; customers who receive wrong items can demand a refund or the supplier has to pay double transportation costs [109]. Delivery errors were explained such as delivery quantities from suppliers that are different than the required quantities [88]. The deliveries of wrong products or deliveries to the wrong directions are also delivery errors [4]. Scanning errors generally occur when a customer wants to buy two similar items with the same price. In order to accelerate the payment process, checkout employee often scans one item twice as if they were identical, which leads to inventory inaccuracy for both items [1]. In a recent study, Sahin and Dallery [118] propose an analytic model to analyze the impact of inventory inaccuracy due to scanning errors.

Shrinkage (named also stock loss) errors include all types of errors that cause loss of products ready for sale. There are several studies on this subject (Bullard and Resnik [22], Brooks *et al.* [18]...). According to a retail survey report of the University of Florida, shrinkage errors represent 1.69% of sales for retailers [63]. Shrinkage errors include employee theft, shoplifting, administration and paperwork errors, vendor fraud [26] [25] and unavailable products for sale [75]. Theft represents an important part of shrinkage errors. There are several studies on internal and external theft in supply chains. According to the previous studies, theft levels represent about 1-2% of total sales (2000 Retail Survey University of Florida [25], the National Supermarket Research Group for 2001 [48]). The products unavailable for sale are called unsaleable by Tellkamp [134]. Lightburn [95] reports that the causes of unsaleable products are damage with 63%, out-of-code with 16% and discontinued items with 12%. He also mentions that according to the results of a survey which included about 65 manufacturers and retailers, the cost of unsaleable food takes 1% of US sales. Chappell *et al.* [26] call unsaleable products as write-offs. They explain that one of its causes is spoilage, caused by time or temperature exposure, and applies to many products in retail supply chains as well as some types of prescription medications.

Inaccessible inventory can be explained as products which are not in the correct place and are not available for customers. Inaccessible inventories, called also misplaced items, have been studied by many authors (Lee *et al.* [91], Camdereli and Swaminathan [23]...). Employees can put products on wrong shelves or customers can set an item that they took from a shelf to another shelf [75]. It can also happen in the back room store [153]. This inaccessible inventory can be found later and be ready to be sold again. If the items are seasonal, and they are found after the season, retailers can discount the price to sell the products [113]. If misplaced items are found too late and become out of date, fashion or season, the inaccessible products become unsaleable products and thus cannot be sold [74]. Raman *et al.* [110]

present a case study where misplaced items reduced profits by 25%.

Literature on supply errors is limited (Yano and Lee [155], Bensoussan *et al.* [14]...). Product quality, yield efficiency and supply process can affect inventory accuracy [111].

A recent survey on the causes of inventory inaccuracy in supply chain management is presented by Delaunay *et al.* [37]. They were interested in the errors of supply chain such as shrinkage, misplacement, supply and transactions errors. They classify the papers in the literature according to the type of errors, the structure of the error modeling (additive, multiplicative or fixed error modeling), the structure of the supply chain (centralized or decentralized) and the objective of the paper (evaluate the impact of errors or optimize the supply chain model).

RFID technologies provide better product traceability through real time data capture properties that enable improvements in the supply chains against these inventory inaccuracy errors [91]. It is in particular very successful to eliminate transaction errors [160]. Although RFID cannot eliminate all errors, they can be detected quickly and by considering the existence of this problem in planning processes, they can be dealt with effectively. Several authors were interested in RFID technologies to be able to eliminate these errors. They analyzed the impact of RFID technologies on inventory inaccuracy due to different errors. Kang and Gershwin [74], Fleisch and Tellkamp [48], Lee *et al.* [91], Sahin *et al.* [117], Rekik [111] and Gaukler [51] are some of them. These papers will be detailed in the next section.

3.3.2 Bullwhip effect

The bullwhip effect is an important phenomenon in supply chain management that has been studied for about fifty years. It was explained by Stevenson [130] that the demand variations of the customer become increasingly large when they diffuse backwards through the chain. The bullwhip effect was first introduced by Forrester [49]. He observed a fluctuation and amplification of demand from the downstream to the upstream of the supply chain. He stated that the variance of the customer demand increases at each step of the supply chain (customer, retailer, distributor, producer and supplier). Furthermore, he concluded that the main cause of this amplification is the difficulties in the information sharing between each actor of the supply chain.

Including Forrester's approach, several authors analyze the sources of bullwhip errors and the factors to control the bullwhip effect. Lee *et al.* [89] present main sources of bullwhip effect such as demand forecast, order batching, price fluctuation and gaming principle. Wang *et al.* [147] conclude that lead time, market sensitivity and resource allocations in supply chains can cause bullwhip effect.

Geary *et al.*[54] review the literature on bullwhip effect and analyze the previous approaches and conclude that the main cause of bullwhip errors is poor material flow. Wamba *et al.* [144] indicate that controlling the bullwhip effect can optimize material resources by decreasing unnecessary locations or safety stocks along the supply chains. Metters [100] quantifies the bullwhip effect in supply chain by comparing the effects of increased demand seasonality and forecast error of demand distortion. They show that eliminating the bullwhip effect can increase profits by an average of 15-30%.

Information sharing is indicated as one of the main factors to control the bullwhip effect. Chen *et al.* [27] develop an analytical approach in order to evaluate the impacts of information sharing between supply chain actors on the bullwhip effect. Holweg *et al.* [64] also indicate that supply chain collaboration and the visibility of information flow can reduce the bullwhip effect that improves service quality, decreases inventory levels and reduces stock-outs.

Several authors conclude that Auto-ID technologies such as RFID can reduce bullwhip effect and improve supply chain performance. Bottani and Rizzi [16] indicate that an automated information system can improve the inventory visibility that can thus reduce safety stocks and the bullwhip effect. Wang *et al.* [147] conclude that RFID integrations into supply chains can reduce bullwhip effect and improve inventory replenishment management performance. Imburgia [71] indicates that RFID technologies can prevent the bullwhip effect through more accurate forecasting. Zaharudin *et al.* [158] indicate that auto-id technologies can reduce the bullwhip effect through information sharing between all supply chain actors by accessing information in a single way. Saygin *et al.* [125] conclude that RFID can reduce bullwhip effect by a better visibility obtained through real-time information of items and locations. However, they highlight that having too much visibility is equivalent to having no visibility because having a lot of unusable data can worsen supply chain performance.

Numerous authors analyze the bullwhip effect. A short list of the publications is given in Table 3.4.

Buffa and Miller [21] deal with the bullwhip effect in planning and control. Sterman [129] describe an effective method to understand the bullwhip effect named as “beer game". It is a useful teaching tool where each participant represents an actor of a beer supply chain such as retailer, wholesaler, distributor and manufacturer. This game has been played many times by numerous students, professionals and managers. Every time, the same results are obtained; a small change in a consumer demand is translated into considerable fluctuation in both orders and inventory up-

Authors	Year	Main topic
Buffa and Miller [21]	1979	Bullwhip effect in planning and control systems
Sterman [129]	1989	Beer game: an effective method to understand the bullwhip effect
De Kok *et al.* [34]	2007	Philips Semiconductor bullwhip effects
Yucesan [157]	2007	Main sources of bullwhip effect
Huang *et al.* [67]	2003	Impacts of information sharing
Choi *et al.* [28]	2008	The importance of information sharing in a virtual enterprise chain
Emerson *et al.* [44]	2009	The information sharing in a dynamic supply chain
Zhou [159]	2009	Benefits of RFID information visibility using a manufacturing example
Agrawal *et al.* [2]	2009	Impact of information sharing and lead time on the bullwhip effect

Table 3.4: List of publications on the bullwhip effect

stream. This fluctuation is caused by the lack of information sharing among the entire chain.

De Kok *et al.* [34] present a study of Philips Semiconductor bullwhip effects. In 1999, Philips conducted a project on bullwhip effects in some of its supply chains and developed a collaborative-planning tool to reduce inventory and increase customer service levels. The results of this project show important savings; minimum yearly savings of around US $5 million is from $300 million yearly turnover. This study presents an insight into complex stochastic problems, such as multi-item multi-level inventory control.

More recently, Yucesan [157] writes that the main cause of the bullwhip phenomenon is the deficiency in information sharing, communication, and collaboration throughout the supply chain that causes information failure as well as delays in information and material flows. Huang *et al.* [67] review the literature of the impacts of shared information on supply chain dynamics. They also discuss how to share information (information, time, people, format, etc) to maximize the benefits for supply chains. According to them, more shared information leads to more efficient decisions on ordering, on capacity allocation and on production planning for each supply chain actor.

Choi *et al.* [28] focus on the importance of information sharing through a new virtual enterprise chain collaboration framework. They analyze the impacts of enterprise collaboration on three aspects: business processes, service components and technologies that are essential for the collaboration of virtual enterprises.

Emerson *et al.* [44] focus on the information sharing in a dynamic supply chain. They consider that the actors of a supply chain can update the knowledge independently when they need to keep the partners informed. They use a knowledge base framework in order to analyze the effects of inventory constraints on the performance dynamics of supply chains. They indicate that neither static nor dynamic configurations are consistently dominant. They show that dynamically choosing a supplier or assembler does not always optimize the profits, but it can be more profitable by choosing the right supplier.

Zhou [159] analyzes the benefit of RFID item-level information visibility using a manufacturing example in multiple periods. He considers the reduced uncertainty as a key factor to increase the benefit in both static and dynamic scenarios. The analysis shows that the benefit due to item-level visibility increases through the improvement of the information system. The results also show that the information visibility in multiple periods can provide improved decision making.

Agrawal *et al.* [2] analyze the impact of information sharing and lead time on the bullwhip effect and inventory levels in a two-level supply chain. They showed that, even if the information is shared inter and intra echelon, it cannot completely eliminate the bullwhip effect. Their results show that lead time reduction is more interesting to reduce the bullwhip effect than information sharing.

RFID technologies can deal with the bullwhip effect by considering supply chain as a whole as well as by reducing drastically the information distortion through data capture and real time communication properties. There are several simulation studies conducted on this subject to analyze the impact of RFID technologies on the bullwhip effect ([72], [127] and [48]). We detail these papers in the next section.

3.3.3 Replenishment policies

In inventory management, replenishment policies are very important methods for determining the frequency and the size of orders to maximize customer satisfaction with low ordering, holding and stock out costs. There are several replenishment policies under continuous or periodic review inventory systems. Companies try to choose the best policy for them. Inventory replenishment decisions are made based on inventory levels in the information system. Real-time inventory information obtained by RFID technologies ensures the accuracy of these levels. Hence, companies may change their replenishment strategies. The effects of RFID technologies on replenishment policies have been studied by many authors. Kok and Shang [34], Lee *et al.* [90] and Kang and Gershwin [74] are some of them. These papers will be detailed in the next section.

In this section, we focused on the main problems of supply chains that RFID technologies can deal with. RFID can improve supply chain performances by increasing inventory availability, improving coordination, saving labor cost, reducing inventory levels, etc. Therefore, companies should rethink their important decisions, such as order policies, replenishment from the backroom processes, inventory locations, taking into account new inventory levels, safety stock levels and sharing information among the entire supply chain.

In the next section, we review the literature according to the methods used to analyze the impact of RFID technologies on supply chain performances and potential benefits of RFID technologies against the problems encountered in supply chains such as inventory inaccuracy problems, bullwhip effect, replenishment policies, etc.

3.4 Different approaches to evaluate the benefits of RFID technologies in supply chains

There are several methods to study a system. Law and Kelton [87] present these methods as showed in Figure 3.2 in two groups; experiments with the actual system and experiments with a model of the system that contains physical and mathematical models.

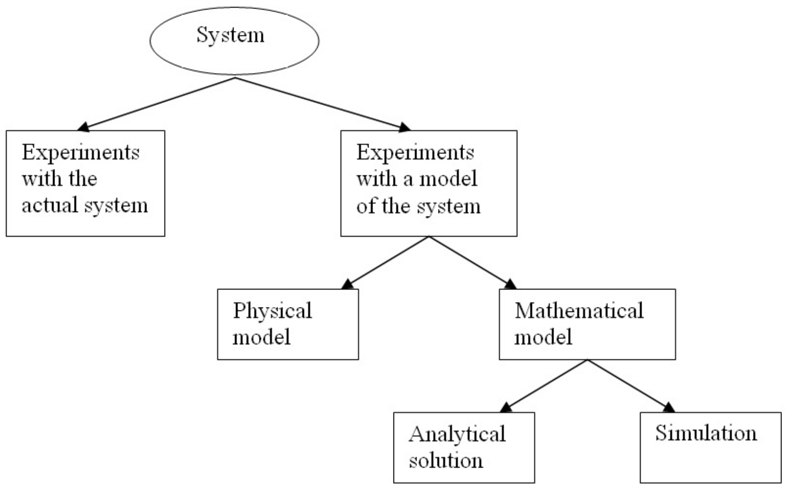


Figure 3.2: Methods to study a system (Law and Kelton [87])

In this section we focus on analytical models and simulations of mathematical models as well as case studies and experiments of physical models subject to potential benefits of RFID technologies.

3.4.1 Analytical models

Analytical models correspond to the simplifications of a real system through mathematical expressions in order to analyze and optimize the system according to an objective function. Analytical models have been studied in supply chain for about four decades. However, the literature on analytical modeling of RFID technologies in supply chain is limited. The main topics that analytical models often deal with are inventory systems with different replenishment policies and Newsvendor models. Table 3.5 summarizes the characteristics of the papers presented in this section.

	Centralized supply chain	Decentralized supply chain	Single item	Multiple items	Periodic review inventory system	Continuous review inventory system	Single Period	Multiple Periods	Replenishment policy
Iglehart and Morey [70]	*		*		*		*		(s,S)
Lee and Ozer [88]	*		*		*		*	*	(s,S), (Q,R)
Kang and Gershwin [74]	*		*				*		(Q,R)
Gaukler *et al.* [50]						*			(Q,R)
Atali *et al.* [6]	*		*		*			*	
Kok *et al.* [33]			*		*			*	(R,S)
Sahin *et al.* [117] [116]	*		*		*		*		Newsvendor model
Rekik *et al.* [111] [113] [114] [112]	*	*	*		*		*		Newsvendor model
Sahin and Dallery [118]			*		*		*		Newsvendor model
Tellkamp [135]	*	*	*		*			*	(s,S) (s,Q)
Gaukler *et al.* [53] [51]	*	*	*		*			*	(Q,R)
Heese [61]		*	*		*		*	*	Newsvendor model
Karaer and Lee [76]	*		*		*			*	Base-stock policy
Sounderpandian *et al.* [128]		*		*	*			*	(s,Q)
Szmerekovsky and Zhang [131]	*	*			*	*	*		
Uçkun *et al.* [138]	*	*	*		*		*		Newsvendor model
DeHoratius *et al.* [35]	*			*	*			*	(s,S)
Sarac *et al.* [119]	*		*		*		*		Newsvendor model

Table 3.5: Characteristics of analytical modeling papers

The first analytical modeling approach on inventory inaccuracy due to transaction errors was presented by Iglehart and Morey [70]. They study a single-item, periodic-review inventory system with a reorder point up-to-level replenishment policy (s, S). They propose a formula to optimize the frequency of physical inventory counting, to correct inaccurate data, and safety stocks in order to protect the system against out-of-stocks.

In a recent paper, Lee and Ozer [88] extend the model of Iglehart and Morey, and they observe that random distribution of transaction errors and uncertain demands make this approach an approximation. They integrate RFID technology to this model. The originality of this study is that, contrary to classical approaches, they do not consider RFID as a perfect technology; they assume that RFID can reduce transaction errors by 90%. They observe that, depending on the error and the demand, this reduction can reduce by around 5.9% the inventory cost related to transaction errors.

Kang and Gershwin [74] also develop an analytical and simulation model of a single item inventory system under a regular replenishment order (Q, R) policy. They have shown that even a small rate of inaccuracy due to undetected stock loss can disrupt the replenishment process and creates severe out-of-stocks. The results are presented in the next section.

Gaukler *et al.* [50] also model the impact of RFID on supply visibility in the (Q, R) policy. They propose a model to analyze how a retailer can use order progress information obtained by RFID in an uncertain replenishment lead time and uncertain demand environment. Based on numerical experiments, they conclude that 47-65% cost savings are gained on the order progress information. They obtain interesting results. However, this study is limited to a single-item and simple supply chain.

Atali *et al.* [6] study a single-item, periodic-review inventory problem on inventory accuracy due to shrinkage (such as thefts and damages), misplacement and transaction (scanning) errors. They develop two models. In the base model, they focus on the impacts of errors on the inventory management. In the second model, they integrate RFID to deal with these errors. They try to analyze whether RFID technologies can improve inventory visibility and if they can eliminate or reduce some of the causes for inventory inaccuracy. The originality of this study is that they consider that RFID can eliminate some of the error sources, but not all of them. Their analyses are limited to a single-stage and single-item supply chain.

Kok *et al.* [33] propose an analytic model to study the impact of RFID technology on inventory management with shrinkage errors. They quantify the potential gains of using RFID against shrinkage errors. The cost-benefit analysis deals in particular with the cost of the technology and the inspection cycle length. Finally, they conclude that the price of the item and the fraction of demand have the largest impact on the break-even costs for RFID tags. The originality of this study is that they indicate that the effect of inspection cycle length depends on the item value and its theft rate. They observe that a long inspection cycle can drastically increase investment if the item value and the theft rate are high. Considering that RFID technologies provide 100% accuracy and not considering the fixed cost (e.g. the reading equipment, etc.) are the limitations of this study.

Sahin [116] focuses on the impact of inventory inaccuracy on the performance of supply chain inventory management. She studies the reasons for inaccuracy and develops a general Newsvendor model in order to analyze inventory inaccuracies and to quantify the cost of errors. Furthermore, she analyzes the economic effect of implementing an advanced auto-ID technology such as RFID. Following this study, Sahin *et al.* [117] develop a single-period model where inventory inaccuracies occur because of the data capture process. In this study, they evaluate the impact of inaccuracies on the inventory system performance and also analyze additional overage and shortage costs. They conclude that not correcting inaccuracies, even if error rates are small, may induce large costs. Furthermore, they observe that, when inaccuracy occurs in inventory management, the cost of having errors may be up to 80%. Analyzing a single-period simple supply chain and considering that RFID technologies provide 100% accuracy are the limitations of this study.

The previous study is again extended by Rekik *et al.* ([111], [113], [114] and [112]). The authors analyzes several models to quantify the impact of inventory inaccuracy on inventory management. They define separately the factors for inventory inaccuracy such as transaction errors, misplaced items, theft, damage and spoilage and supply errors. They deal with each factor separately and analyze the effect of RFID technology on supply chain inventory through a newsvendor model. They consider RFID as a perfect technology that can eliminate all errors. In a recent paper, Rekik *et al.* [112] analyze a single manufacturer, single retailer, single product Newsvendor model subject to execution problems such as losses in the backroom and misplacements in the store. They analyze two models; in the first model, supply chain actors are aware of the errors and take them into consideration in their order decisions and, in the second model, they integrate RFID technology within the store to eliminate errors. They observe that, when more errors occur in the system, RFID provides more benefits for both manufacturer and retailer as well as for the entire supply chain. They conclude that the benefits are larger with RFID technology when shelf availability is poor. These studies are limited to a single-product and single-period supply chain. Considering inventory errors separately makes their models not realistic enough.

Sahin and Dallery [118] also study a Newsvendor model in which inventory inaccuracy occurs because of the data recording errors. They consider that actors of the studied chain use barcode labels and scanners in order to obtain inventory level information. They analyze the economic impacts of inventory inaccuracy by comparing two models. In the first, inventory errors are ignored. In the second model, they consider that a new data capture technology such as RFID is integrated that eliminates the recording errors. The originality of this work lies in the study of the economic impacts of inventory inaccuracy in terms of overage/underage costs and the savings through error elimination and introducing a new cost factor, i.e. shortage penalty, related with demands that were accepted by the actor but could not be satisfied. They present interesting results that are however limited to single-period and single-item inventory models.

Tellkamp [135] proposes an analytical model to analyze the potential impact of RFID on product availability. According to the author, providing inventory accuracy and reorganizing the replenishment are the most interesting subjects. Through the analytical model, he finds that inventory inaccuracy decreases service level by about 7% and also decreases the values of reorder points.

Gaukler [51] studies the effects of RFID technologies on supply chains at three decision levels; strategic, tactical and operational. He develops an analytical model to analyze the cost of RFID technology and also its benefits. He assumes that the price of RFID technologies can be shared by all actors of the supply chain. He also considers the use of these technologies to improve stock control policies as well as inventory replenishment policies. A numerical study is conducted to evaluate the cost savings due to a more effective reorder point replenishment policy. The results show that RFID can reduce costs by about 2.8%-4.5%. He develops significant analyses, but only considers a single-product and simple supply chain is the limitation of this study.

In a recent paper, Gaukler *et al.* [53] analyze the benefits and the costs of an item-level RFID application in a supply chain which contains one manufacturer and one retailer. They develop two analytical models; a centralized case with and without RFID at item level and a decentralized case with item level tagging RFID where the manufacturer and the retailer try to optimize their own profit without cooperation. The centralized model is first studied and the level of tag prices which make item-level RFID economically feasible is estimated. The service level is considered to be a key performance factor, because a high tag price decreases the retailer's backroom inventory level which can in turn reduce the service level. The impact of an item-level RFID implementation on the decentralized model is then studied in order to evaluate how the tag cost should be shared between the supply chain actors. Their analyses show that, when the manufacturer is dominant, sharing RFID costs between the actors is not a matter. However, they also indicate that, when the retailer is the driving force, there exists an optimal sharing of the tag cost to maximize the retailer and the supply chain profit which depends on the retailer's power to mandate the manufacturer a lower profit. They present interesting analyses, that are limited in a "simple" two-level supply chain is the limitation of this paper.

Heese [61] analyzes the impacts of inventory accuracy and RFID adoption in a decentralized supply chain. Similarly to most papers in literature, he considers that RFID technologies can eliminate all shrinkage errors. However, he indicates that RFID technologies are more beneficial in decentralized supply chains.

Karaer and Lee [76] focus on the value of inventory visibility obtained through RFID technologies in the reverse channel management. They analyze the coordination of the reverse and forward chain at the distribution center of a manufacturer. The results of their analytical approach show that RFID technologies provide several benefits that depend mainly on the volatility of product return and the duration of the reverse of the reverse channel processes.

Sounderpandian *et al.* [128] are interested in the costs and benefits of implementations of RFID technologies in a supply chain that contains a manufacturer, a distributor, a retailer and consumers. They develop an analytic approach in order to estimate the load rate of RFID employment by the retailers and the cost benefits obtained through RFID applications for shelf replenishment. The main originality of this study is that they consider RFID technology application at item, case, and pallet levels and the costs of RFID implementation include tag reader costs, communication costs and other infrastructure costs. They note that RFID can improve the automatic checkout process at retail store, so it can reduce inventory costs as a result of more efficient shelf replenishment. They also observe some additional benefits of RFID such as reduction losses due to shoplifting and increased use of point of sale applications. They analyze a simple supply chain. However, practical supply chains are more complicated. They would obtain more realistic results by analyzing supply chains with multiple actors.

Szmerekovsky and Zhang [131] analyze the impacts of RFID technologies on a Vendor Managed Inventory (VMI) system using an analytical approach. They develop two single-period models with one manufacturer and one retailer. The first model considers a basic inventory management system under a periodic replenishment policy and, in the second model, an RFID system is integrated and a continuous review replenishment policy is used. They first determine the optimal policies and then compare the performances of these models in a centralized system where the objective is to maximize the overall supply chain profit. They show that implementing RFID can increase sales and inventory levels. They add that the efficiency of RFID depends on the tag price and available shelf space. They also analyze the effect of RFID on the manufacturer and the retailer in a decentralized system. They observe the utility of sharing the tag cost between the manufacturer and the retailer. In their model, they only consider the variable costs associated with RFID technology. Analyzing a simple two-level and single-period supply chain and not considering the fixed costs of RFID are the main limitations of this study.

Uçkun *et al.* [138] use an analytic model to study the deployment of RFID technologies in a two-level supply chain which contains a supplier and a retailer. They analyze the optimal investment levels of RFID, the benefits of RFID gained through more accurate inventory, the system parameters that make the investments more profitable and the effect of inventory sharing on the investment decision. As an extension to this study, Uçkun *et al.* [139] focus on the optimal investment level that maximizes the profit in both centralized and decentralized supply chains. Through a single-period newsvendor analytic approach, they study a three-level supply chain that contains a retailer, a supplier and multiple warehouses. They first develop a model under two scenarios. In the first one, inventory sharing between the warehouses is allowed whereas, in the second scenario, sharing is not allowed. Their model deals with inventory inaccuracy problems due to shrinkage and misplacement errors and they consider that RFID technologies can eliminate these errors. They then study several extensions of this model; asymmetric warehouse parameters, demand and inventory correlation and imperfect RFID implementation. The numerical results show that the profit difference between the decentralized and the centralized system is sharp when the profit margin of the retailer is low and inventory sharing is not allowed. They also observe that, if there is no inventory sharing between warehouses, making an investment to decrease inventory accuracy is more beneficial. Finally, they characterize the important factor for the investment decision as low fixed investment costs and small demand variances. They present interesting analyses that are however limited to simple supply chain. RFID technologies are again considered as perfect technologies.

DeHoratius *et al.* [35] analyze a two-level, multi-period inventory system. The originality of this study is that they consider an intelligent inventory management tool using a Bayesian analysis of the physical inventory level. They assume that records can be inaccurate and excess demands are lost and unobserved. They demonstrate that a Bayesian inventory record is an efficient alternative method that can provide good replenishment policies and the required parameters can be estimated from existing data sources. Their results are limited to a simple two-level supply chain.

Sarac *et al.* [119] analyze the impacts of RFID technologies on a newsvendor model that contains inventory inaccuracy because of out of stocks due to misplacements, thefts, expired and obsolete products. This study considers, contrary to numerous papers in the literature, that RFID technologies are not perfect and their efficiencies increase with the costs of RFID technologies. An analytic model is proposed to examine how RFID technology can decrease the inventory inaccuracy and to calculate the most profitable technology cost. The results show that there is a certain RFID cost that makes the profit optimum. This cost is proportional to the price of the product as well as its ordered quantity.

In this subsection, we reviewed the analytical models dealing with RFID applications in supply chains. Most of these models consider simplified supply chains that contain a single product, a single period, a single manufacturer, etc. Furthermore, the majority of these models consider RFID technologies as a perfect technology that can eliminate all problems.

In analytical models, various hypotheses and approximations are considered. Thus the results of these models are limited. However, simulations provide better observation of a real system to analyze its performances and behaviors over time. In the next subsection we present simulation models that consider RFID integrations in supply chains.

3.4.2 Simulation models

Simulation provides better understanding of complex models with a sense of dynamics of the systems. Numerous authors review the necessary steps to perform a simulation study. Banks *et al.* [10] present these steps as in Figure 3.3.

According to this approach, the model should first be formulated with the statement of objectives and of alternative systems. The model is conceptualized and the required input data is collected. The model is then programmed in a simulation language. In order to pass the experimental design step, the selected computer program efficiency must be verified and the model has to be validated if it represents the actual system behavior. In the next step, production runs and their analyses are used to evaluate the performance measures for the system design. Additional runs are performed if it is necessary. At the end, in order to obtain a successful implementation, the results of all analyses must clearly be saved. Through these steps, we notice that through several verification steps simulation studies can provide more realistic analyses of systems than analytic models.

The literature of simulations on RFID applications in supply chains has increased in the last few years. Table 3.6 presents a short list of the publications analyzed in this section.

One of the first studies on supply chain simulation is performed in Krajewski *et al.* (1987) [83]. Authors simulate an MRP based production environment to analyze the factors of inventory management performance. They use some performance measures such as inventory level, percentage of late orders, etc. More recently, Brown *et al.* [20] also simulate a MRP environment in order to analyze the impact of inventory inaccuracy. They focus on the frequency, the magnitude and the location of errors that cause inventory inaccuracy; which represent respectively the number

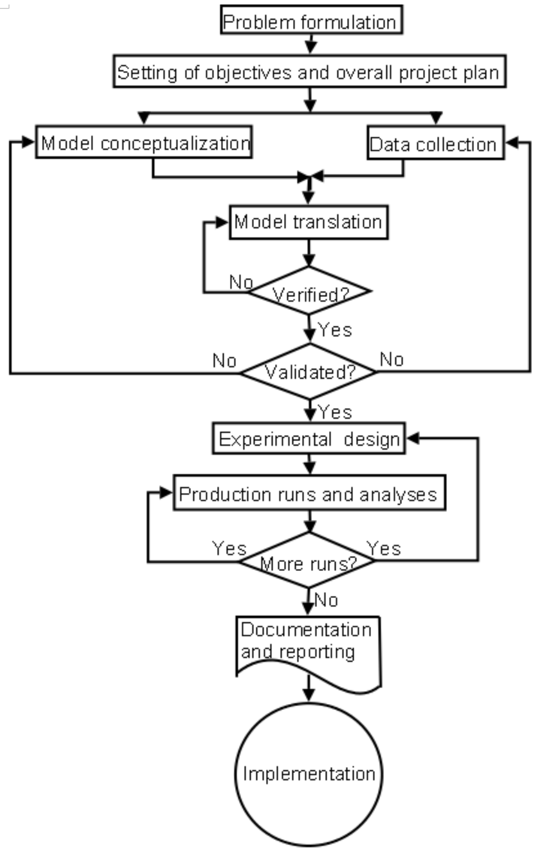


Figure 3.3: Steps in a simulation study (Banks *et al.* [10])

of time periods of inaccuracy, the percentage of inaccuracy and the processes where inaccuracy occurs. They conclude that the frequency of errors is the main factor of inventory performance. However, the magnitude and the location of errors can also affect the supply chain performance.

Joshi [72] uses a simulation approach to evaluate the value of information visibility in a supply chain using RFID. He underlines that information visibility is one of the success factor of software implementations. He deals with the "bullwhip effect"; and he simulates a simple supply chain with different scenarios. He varies the degree of information visibility and collaboration between supply chain actors as if RFID technologies were deployed in the system. The results he obtains show that information visibility and collaboration provide 40-70% reduction in inventory costs. He also concludes that the reduction in lost sales improves customer service due to timely order deliveries and real time traceability. Analyzing a simple supply chain is the main limitation of this study.

Authors	Year	Title
Krajewski *et al.* [83]	1987	Kanban, MRP, and shaping the manufacturing environment
Brown *et al.* [20]	2001	Measuring the effects of inventory inaccuracy in MRP inventory and delivery performance
Joshi [72]	2000	Information visibility and its effect on supply chain dynamic
Kang and Koh [75]	2002	Applications research
Kang and Gershwin [74]	2004	Information inaccuracy in inventory systems-stock loss and stockout
Lee *et al.* [90]	2004	Exploring the impact of RFID on supply chain dynamics
Fleisch and Tellkamp [48]	2005	Inventory inaccuracy and supply chain performance: a simulation study of a retail supply chain
Basinger [13]	2006	Impact of inaccurate data on supply chain inventory performance
Leung *et al.* [93]	2007	A tool set for exploring the value of RFID in a supply chain
Saygin [124]	2007	A systems approach to viable RFID implementation in the supply chain
Sarac *et al.* [121]	2008	A simulation approach to evaluate the impact of introducing RFID technologies in a three-level supply chain
Wang *et al.* [147]	2008	The simulated impact of RFID-enabled supply chain on pull-based inventory replenishment in TFT-LCD industry
Kim *et al.* [80]	2008	Value analysis of location-enabled radio-frequency identification information on delivery chain performance
Yoo *et al.* [156]	2009	Service level management of nonstationary supply chain using direct neural network controller
Vrba *et al.* [142]	2008	Using radio frequency identification in agent-based control systems for industrial applications
Ustundag and Tanyas [140]	2009	The impacts of Radio Frequency Identification (RFID) technology on supply chain costs
Wamba *et al.* [143]	2008	RFID-Enabled warehouse optimisation: Lessons from early adopters in the 3PL industry

Table 3.6: List of publications that develop simulation analyses

Kang and Koh [75] simulate a retailer inventory system. The model includes an automatic reorder point replenishment policy, random demand and inventory inaccuracy due to shrinkage errors. They show that 2.5% increase of shrinkage can increase stock out rate by about 50%. They also conclude that the indirect cost of uncounted shrinkage errors that cause stock outs is 30 times greater than the direct cost of shrinkage errors.

Kang and Gershwin [74] also study the impact of shrinkage errors on inventory management. They consider indirect costs such as losses of potential customers that occur because of unexpected out-of-stocks and also direct costs due to inventory losses. They simulate a single item inventory model with a periodic review system under a (Q, R) policy to analyze the effects of shrinkage errors on lost sales. In this simulation, they observe that even a 1% shrinkage error can cause an out-of-stock level at 17% of the total lost demand, as well as 2.4% of shrinkage can increase the out-of-stock level to 50%. To eliminate inaccuracy, they also examine several inventory management methods such as safety stock, manual inventory verification, manual reset of the inventory record, constant decrement of the inventory record, Auto-ID technologies and they conclude that each method has different limitations.

However, assuming that Auto-ID provides perfectly accurate inventory and studying a single-item model is not realistic enough.

Lee *et al.* [90] realize a quantitative analysis to demonstrate the potential benefits of RFID in inventory reduction and service level improvement. They conclude that RFID can impact some performance factors of the supply chain. They focus on analyzing the effect of factors such as inventory accuracy, shelf replenishment policy and inventory visibility. They show that RFID implementation can reduce distribution center inventory level by 23% and eliminate completely backorders. They conclude that RFID can also provide a reduction in order quantity that can reduce distribution center inventory level by up to 47%. Again, in this study, RFID technologies are considered to provide 100% accuracy.

Fleisch and Tellkamp [48] simulate a one-product three-level supply chain to analyze the impact of different causes for inventory inaccuracy on supply chain performance. They develop two models. In the base model, inventory inaccuracy occurs because of some factors such as low process quality, theft, and items becoming unavailable for sale and there is not any alignment policy to adjust the wrong information of inventory level. In the modified model, inventory inaccuracy is still present but, at the end of each period, inventory records are aligned. The result of their simulation indicates that an elimination of inventory inaccuracy can reduce out-of-stock level and supply chain cost even with a small initial inventory inaccuracy of 2%. They show interesting results that are however limited to a one-product supply chain.

Basinger [13] develops a simulation of a single item, three-level supply chain subject to inventory inaccuracy and its impact on supply chain performance. He finds that dominance factors of inaccuracy are the order policy, “stock out/backlog" policy, theft and supply chain synchronization. The results show that the “stock out/backlog" policy has the most impact on the service level, followed by the order policy. He reports that physical inventory counting is a method frequently used to align physical and recorded inventory levels. He concludes that RFID is a new method for real-time alignment of the data that can improve the accuracy of supply chain inventory. Single-item modeling and single setting for the expected demand conditions are the limitations of this study.

Leung *et al.* [93] develop a simulation to analyze the impact of RFID on supply chain management. They focus on shrinkage errors that cause inaccuracy. They simulate two models; with and without RFID. They assumed that RFID can eliminate the inaccuracy by 100%. The results obtained show that the backorder quantity decreases by 1% and the average inventory increases by 20%. They also observe that RFID can decrease inventory levels. The originality of this study is that they detail the investment data of RFID technology and its benefits related to inventory shrinkage. However, this study is limited again by considering RFID as a perfect technology and focusing only on the logistics of the supply chain.

Saygin [124] deals with RFID technology implementations on the inventory management of time-sensitive materials in a simulation environment. He compares four inventory models in order to analyze the impacts of RFID technologies in a complex decision-making manufacturing system. The models are simulated through the Rockwell Arena simulation package and, in each model, the statistical analysis of the performance are obtained by using Analysis of Variance (ANOVA). He demonstrates that RFID technologies can provide important benefits by decreasing manufacturing costs with a higher service level and lower inventory and waste levels. In this study, he considers that RFID technology provides 100% visibility of inventory levels.

Sarac *et al.* [121] analyze the impacts of RFID technologies, particularly their economical impacts and ROI analyses on supply chain performances. They develop a simulation model of a three-level supply chain with inventory information inaccuracies because of thefts, misplacements and unavailable items for sale. The effects of different RFID technologies and with different tagging levels for different product types were examined. The main originality of this research is that various RFID systems of different costs and potential profits are analyzed and the possibility of RFID errors is not ignored. The results show that different technologies can improve the supply chain performance at different ratios and the economical impacts and also ROI analyses depend on the chosen technology, the tagging level and the characteristics of the products.

Wang *et al.* [147] analyze the impacts of RFID technology in the thin film transistor liquid crystal (TFT-LCD) industry. They develop a simulation model of a pull-based multi agents supply chain where an automatic inventory replenishment policy (s, S) is enabled with and without RFID technology. They obtain interesting results which show that RFID technology integration to the automatic replenishment policy can reduce the total inventory cost and increase the inventory turnover rate.

Kim *et al.* [80] deal with the value of RFID real-time information for vehicle deployment and shipment process on delivery chain performance. They develop three simulation models. In the first model, data for vehicle deployment and shipment are collected manually. RFID technology is integrated in the second model to collect real-time data. In the third model, they propose a new planning algorithm that uses RFID technology to provide real time information automatically. Their simulation study results show that the integration RFID technology to the tracking system can improve customer satisfaction by decreasing dwell time and can reduce labor cost by increasing labor utilization. They also indicate that RFID-based information systems can provide better decision-making using real-time information. Their analyses are interesting but limited to a simple three-level supply chain.

Yoo *et al.* [156] develop a simulation model of a three-level closed loop supply chain to analyze the value of RFID real-time information on the performance of a direct neural network controller. They indicate that a neural network controller is an intelligent decision maker that aims to keep the actual service level close to the target level under an unstable customer demand. They consider that RFID technology can provide the required data for the neural network controller during the operations of the supply chain. Their simulation results show that, using RFID technology, the direct neural network controller can make the actual service level reach the target level in a short time with small average errors. The originality of this study is that they analyze a supply chain that contains multiple actors. However, considering that RFID technologies provide 100% the information accuracy.

Vrba *et al.* [142] analyze the deployment of RFID technologies in industrial applications for the real-time programmable logic controller (PLC) - based manufacturing control. They develop a simulation model of RFID integration to an agent based control system. Special RFID agents were introduced as mediators between the physical readers and other control agents. The RFID data was used by resource agents such as machines, transport system components to discuss the details of production and transportation. The originality of this study is that the proposed model was verified in the lab environment using the Manufacturing Agent Simulation Tool system.

Ustundag and Tanyas [140] perform a simulation study to analyze the benefits of RFID system integration on a three-echelon supply chain. They consider that RFID systems can improve the efficiency, accuracy, visibility, and security level in supply chains. They focus on the product value, lead time, and demand uncertainty as the cost factors of the chain. Their simulation results show that the augment in product value increases the total supply chain cost saving and the increase of demand uncertainty decreases the cost savings. They also show that supply chain actors do not gain equally from RFID integration and the retailer has the highest cost savings. The increase in lead time decreases the cost saving of the retailer. The increase in product value and the decrease in the demand uncertainty augment almost equally the cost savings for the distributor and manufacturer. The limitation of this study is that RFID technologies completely delete thefts, misplacements and shipment errors.

Wamba *et al.* [143] focus on RFID technologies in the picking and shipping process of one warehouse in third party logistics companies. They perform a simulation study to analyze the impacts of RFID technologies integration on business processes.

The originality of this study is that they show that RFID technologies can support the redesign of business processes, improve data quality, real-time data collection, synchronization and information sharing between actors. In their study, they consider that the tagging process is done during the picking process. They conclude that the full benefits of RFID technology can be obtained through its integration in all supply chain actors.

Tu *et al.* [136] analyze the performance of RFID technologies in a healthcare system. They propose and simulate different algorithms for locating RFID tagged objects and they analyze RFID benefits on this system. The originality of this study is that, contrarily to general publications, they consider that RFID technology performance depends on environment properties, tag orientations, etc. They present interesting results that are however limited because of simplified assumptions.

In this subsection, we reviewed simulation models of RFID deployments in supply chains. Most of these studies focused on single item, single manufacturer and single retailer supply chains. Through simulation methods, dynamic behavior of the systems can be analyzed. However, simplified models may lead to worst results. In the next subsection, we consider case studies and experiments that can point out key factors of RFID deployments in supply chains.

3.4.3 Case studies and experiments

Case studies and experiments are tests of RFID technologies in small or simple environments. They help companies to show the difficulties and the efficiency of the integration. Moreover, companies can also evaluate some of the associated costs and profits. These applications facilitate the implementation decision as well as the complete integration in the company. Silver *et al.* [126] highlight the importance of realistic models as an important tool for decision making.

There are numerous industrial applications. However, in this section, we focus on the academic papers that deal with case studies and experiments. In the literature, questionnaires and interviews are frequently used in case study papers in order to analyze the point of view of the supply chain actors on the RFID technology, the feasibility and the difficulty of its adoption.

Numerous authors conduct case studies and experiments to analyze the impacts of RFID technologies on supply chains. Table 3.7 is a short list of the publications detailed in following.

Lefebvre *et al.* [92] develop a pilot study to analyze RFID deployment in the warehouse of a specific supply chain. They collected empirical data from four interrelated firms from three echelons of the supply chain. Their results show that RFID

Authors	Year	Title
Lefebvre *et al.* [92]	2006	RFID as an Enabler of B-to-B e-Commerce and its Impact on Business Processes: A Pilot Study of a Supply Chain in the Retail Industry
Tzeng *et al.* [137]	2008	Evaluating the business value of RFID: Evidence from five case studies
Wang *et al.* [146]	2007	Dynamic mobile RFID-based supply chain control and management system in construction
Hou and Huang [66]	2006	Quantitative performance evaluation of RFID applications in the supply chain of the printing industry
Ergen *et al.* [45]	2007	Life-cycle data management of engineered-to-order components using radio frequency identification
Ngai *et al.* [103]	2007	Mobile commerce integrated with RFID technology in a container depot
Chuang and Shaw [31]	2007	RFID: Integration stages in supply chain management
Lin *et al.* [96]	2006	Using RFID in supply chain management for customer service
Huber *et al.* [69]	2007	Barriers to RFID adoption in the supply chain
Huber and Michael [68]	2007	Vendor perceptions of how RFID can minimize product shrinkage in the retail supply chain
Manik *et al.* [97]	2007	Analysis of RFId application through an automotive supplier's production processes
Delen *et al.* [38]	2007	RFID for better supply-chain management through enhanced information visibility
Mourtzis *et al.* [102]	2008	Supply chain modeling and control for producing highly customized products
Baars *et al.* [7]	2008	Combining RFID technology and business intelligence for supply chain optimization - scenarios for retail logistics
Bottani and Rizzi [16]	2008	Economical assessment of the impact of RFID technology and EPC system on the fast-moving consumer goods supply chain
O'Leary [106]	2008	Supporting decisions in real-time enterprises: Autonomic supply chain systems
Kim *et al.* [79]	2008	Comparison of benefits of radio frequency identification: Implications for business strategic performance in the U.S. and Korean retailers
Hossain and Prybutok [65]	2008	Consumer acceptance of RFID technology: An exploratory study
Pigni and Ravarini [107]	2008	RFId in the fashion industry: Evidences and lessons learnt from an anti-counterfeiting project
Poon *et al.* [108]	2009	A RFID case-based logistics resource management system for managing order-picking operations in warehouses

Table 3.7: List of publications that conduct case studies and experiments

technology can be difficult for the actors to apply because it can improve the existing processes, can provide a new business model and can increase the communication between supply chain actors.

Wamba *et al.* [144] analyze the impacts of integrating RFID technologies and EPC network on mobile business to business e-commerce. They carried out a pilot project by testing various scenarios based on empirical data that was obtained from four different companies. They indicate that RFID-EPC network can enhance the operational processes such as shipping, receiving and put-away processes. They note that RFID adoption forces supply chain actors to change their business processes through automated activities, a high level information sharing and a better synchronization between supply chain actors.

Tzeng *et al.* [137] analyze the business value of RFID technology implementation in health care industry. They discuss five case studies with five hospitals in Taiwan in order to identify the organizational effects, strategic impacts and business values of RFID in health care systems. They indicate that RFID employment can significantly change processes and human resources of the organizations, enhance customer satisfaction and improve efficiency and flexibility of process redesign. They note that re-engineering application optimizes systems but its effectiveness is difficult to estimate because of the uncontrollable factors and psychological elements of the organizations. They also highlight the importance of collaboration and cost sharing between all actors of the healthcare supply chain to maximize the efficiency of RFID technology implementations.

Wang *et al.* [146] focus on how RFID technologies can improve the information flow of a construction supply chain environment. They analyze a high-tech factory building in Taiwan in order to verify the proposed RFID-based dynamic construction supply chain model and to test the effectiveness and efficiency of information sharing for project control in the construction phase. They demonstrate that, through real time information, RFID technology can significantly improve supply chain control and construction project management by improving the efficiency of operations and also by providing a dynamic control.

Hou and Huang [66] develop an empirical study through questionnaires and interviews to analyze the costs and benefits of RFID applications in the supply chain of the printing industry. They examine the feasibility of RFID deployments through interviews of eight main actors of the Taiwanese printing industry. They propose interesting models with varying complexity and provide quantitative cost and benefit analyses of RFID technologies integration.

Ergen *et al.* [45] study intelligent components in engineered-to-order (ETO) management. They propose to use RFID technologies so that intelligent components can communicate their identity, location and history with their environments. In order to analyze the technical feasibility of RFID technology for the intelligent components in construction supply chains, they applied three experiments in three types of components. The originality of this study is that, by using various components under several scenarios, they demonstrate the technical feasibility of RFID technology in supply chains. They also indicate that active UHF RFID technology is efficient to create intelligent components.

Ngai *et al.* [103] analyze a case study on RFID technology integration in a mobile commerce system. In this study they conduct the research and development of an RFID prototype system on a local depot to analyze the impacts of RFID system on locating, tracking and managing of the containers in the depot. Through this case study, they observe that RFID technologies improve visibility, decrease errors and accelerate operational processes that enhance customer service quality and save operational, return and pick-up costs. This study presents interesting analyses, but they could evaluate the economical impacts of RFID technologies, for example through ROI analyses.

Chuang and Shaw [31] focus the RFID integration in supply chains. Three different stages of RFID implementation are proposed; functional, business and inter-company RFID integration. They indicate that these stages have different risk and benefit degrees. For each stage, they analyze a company RFID adoption case in order to demonstrate the difficulties and the benefits or a real deployment.

Lin *et al.* [96] analyze an RFID business adopting, and the relationship between RFID and customer relationship management (CRM). They propose an RFID-CRM model in supply chain management and show that RFID technologies can improve customer satisfaction.

Huber *et al.* [69] focus on the impact of RFID on the shrinkage problem for tracking goods, in particular at case-level and item-level. They analyze the challenges and the difficulties of the adoption of RFID technologies in supply chains using interviews of RFID vendors.

Huber and Michael [68] study how RFID can decrease shrinkage problems in the retail supply chain. Interviews with nine Australian RFID vendors and associations are used in this research. The results show that RFID can minimize losses in the supply chain. They indicate that the visibility of stocks is the main shrinkage factor that RFID can improve. The authentication capacity is also defined as a key factor of RFID during recalls, identifying products and against fraud acts. They note that the automation of supply chain processes by RFID technology minimizes human errors. They also add that RFID can decrease the retailer loss by recognizing damaged products because of incorrect temperatures in storage and transportation, expiration dates of products, etc.

Manik *et al.* [97] conducted an RFID application project in an automotive industry supplier company to improve the efficiency of the production process. Through the functional experiment, they observe the advantages of RFID system and to analyze the operational experience and the actual implementation cost.

Delen *et al.* [38] conduct a case study to analyze the impacts of RFID technologies on supply chain management. They study on a simple retailer supply chain in which the retailer use an RFID technology to collect the data of the cases shipped by its major suppliers. They indicate that RFID technologies can improve the performance of entire supply chain but the key factor of the efficiency is not only the technology itself and also the creative use of the data obtained by this technology.

The main originality of this study is that they show that RFID is not a perfect technology. They also highlight the importance of data filtering process to improve the efficiency of RFID implements.

Mourtzis *et al.* [102] deal with the use of RFID technology in a highly customizable production supply system in order to dynamically assure the communication between actors by using real time information to verify the availability of parts required for production. Through a case study in the automotive industry, they demonstrate a software system to analyze the feasibility of RFID integration in the automotive supply chain. They indicate that RFID significantly reduces the order to delivery time so that customization orders can be realized in spite of market variation.

Baars *et al.* [7] analyze the feasibility of a decision support system based on RFID technology and the business intelligence in supply chain management. They use a case study of a three-level retail supply chain which contains Chinese manufacturers, a consolidator who deals with the bundling and the shipment of products in containers from different suppliers in China, and a Goods Distribution Centre (GDC) in Germany. They indicate that cooperation between the business intelligence and RFID technologies enhances supply chain operations, but a cost-benefit analysis should be realized.

Bottani and Rizzi [16] analyze the economical impact of RFID technology on the fast-moving consumer goods (FMCG) supply chain. They focus on a three-echelon supply chain which contains manufacturers, distributors and retailers of FMCG. They collected quantitative and qualitative data of the logistics processes of each actor through a questionnaire survey to examine the feasibility of RFID and EPC adoption, for each echelon of the chain and for the whole chain. The originality of this study is that they show that RFID and EPC deployment is still not profitable for all of the actors. They indicate that, both in the integrated and non-integrated scenarios, RFID technologies at pallet level can provide benefits for all echelons. However, manufacturers cannot obtain positive revenues because of the high cost of case level tagging.

O'Leary [106] highlights RFID technologies as one of the technologies and architectures that can provide real time information and autonomic supply chain. Knowledge-based event managers, intelligent agents, database and system integration, and enterprise resource planning systems are the other reviewed technologies. They analyze two applications of Procter and Gamble and tainted dog food and spinach that demonstrate real-time decision support systems and autonomic system architectures.

Kim *et al.* [79] compare the benefits of RFID technology on supply chain management of U.S and Korean retailers. Through the interviews of numerous U.S. and Korean retailers, they estimate a path model to analyze technological infrastructure, RFID benefits and business strategic performance. Their results indicate that data system automation is a key factor to improve inventory management for both countries. They note that hardware and software applications influence RFID benefits in inventory management for U.S. retailers while, for Korean retailers, it can improve the efficiency of store operation and demand management. They also show that business strategic performance is a main RFID benefit factor for both U.S. and Korean retailers.

Hossain and Prybutok [65] analyze the factors of consumer acceptance of RFID technology. They develop and test a theoretical model with a technology acceptance model. Through interviews of consumers, they indicate that convenience, culture, and security are significant elements of the consumer acceptance of RFID.

Pigni and Ravarini [107] analyze the effects of RFID technologies in the fashion industry. They perform a case study in the Italian fashion industry that includes the gray market and the product distribution. They show that RFID technology integration improves the system business process and provides an inter-organizational information system that improves the efficiency and effectiveness of the entire supply chain.

Poon *et al.* [108] analyze and perform a case study on RFID technology integration in a warehouse in order to facilitate the collection and sharing of inventory data. They aim to formulate and suggest the most effective RFID solution in a warehouse environment. The originality of this study is that they study the actual environment of the warehouse and they propose various RFID technologies (different sizes, costs, reading performances, and application domains) according to properties of the environment. They evaluate the reading performances of active and passive RFID technologies through four tests (orientation, height, range and material). The results of these tests help to select the most efficient RFID equipment and to install the equipment in the most suitable locations for data collection in the warehouse environment. They also verify the data capture capability of the selected RFID technology in three steps; data collection, data storage and data management. They propose three technologies that improve the efficiency of the warehouses by facilitating real-time information sharing and solving communication problems along the supply chain, also by transferring raw data to material handling solutions. Finally, they practice the proposed system in a real working case with three main objectives; simplifying RFID integration, improving the visibility of warehouse activities and the performance of the warehouse.

In this section, we presented the literature on RFID applications in supply chains using analytical models, simulations, or case studies and experiments. These methods can be used in conjunction to analyze impacts, difficulties and effectiveness of RFID technologies in supply chains. In addition to all of these methods, Return-On-Investment (ROI) analyses can be carried out to determine the economical impacts of RFID deployments. The next section surveys the literature on ROI analyses related to RFID applications in supply chains.

3.5 ROI (Return On Investment) analyses of RFID implementations in supply chains

ROI analyses are conducted to evaluate whether an investment is profitable over a period of time. They have often been studied through analytical models, simulations, case studies and experiments. However, the literature on this subject is limited. In this section, we first highlight the importance of ROI analyses. We then present how we can calculate ROI and how to obtain a positive ROI can be obtained. Finally, we present some ROI applications on RFID projects.

3.5.1 Why are ROI analyses so important?

As mentioned before, RFID technologies can provide several benefits on supply chains; cost reduction such as labor cost, inventory cost, process automation, or efficiency improvements and value creation such as increase in revenue, or increase in customer satisfaction [154]. Leung *et al.* [93] present the benefits of RFID as in figure 3.4. This figure shows the benefits of RFID in three main groups; revenue, operating margin, capital efficiency. We observe that there are several benefits of RFID technologies through the increase in revenue, the decrease in operating costs and expenses and the improvement in capital through the reduction of property, plant and equipment costs and inventory costs.

However, the cost of RFID is still larger than current identification technologies [161]. Furthermore, RFID implementations require large costs, that Banks *et al.* [11] divide in 6 groups; hardware costs, software costs, system integration costs, installation services costs, personnel costs and business process reengineering costs. Figure 3.4 presents the main costs of RFID implementations.

Previous figures show that there are several significant costs and benefits of RFID implementations. Thus, companies must decide whether to invest or not to acquire RFID technologies. Hence, ROI analyses are helpful to support decisions on the feasibility of RFID deployments [48].

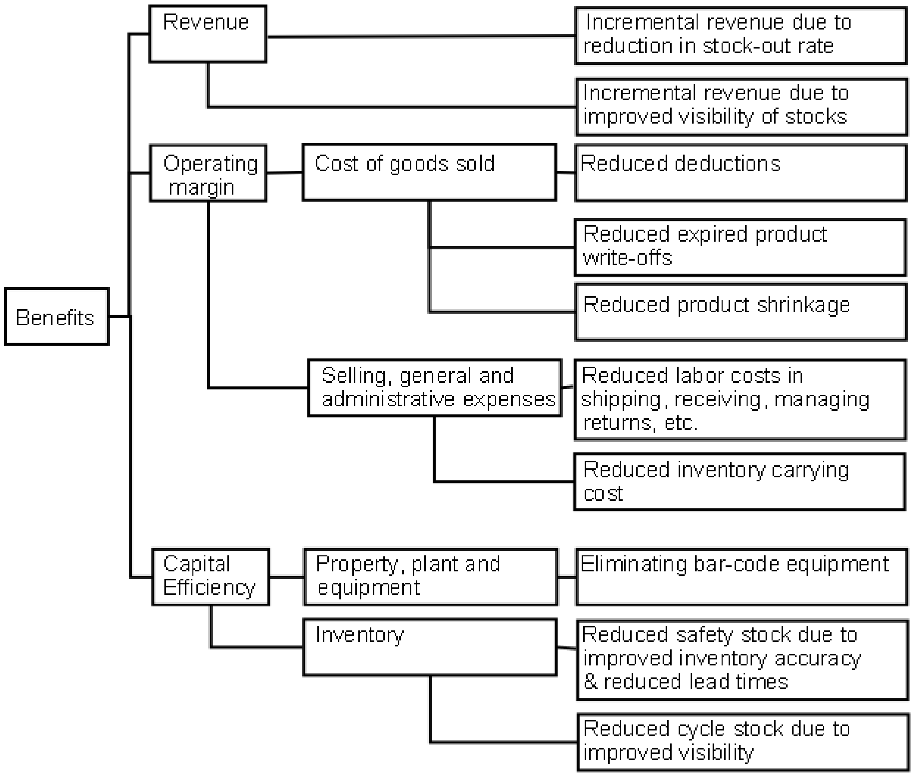


Figure 3.4: RFID benefits (Leung *et al.* [93])

3.5.2 How to calculate ROI?

Equation 3.1 recalls the simplest formula to calculate ROI.

$$\text{ROI} = (\frac{\text{The final monetary yield of the project}}{\text{The investment required by the project}} - 1) * 100 \tag{3.1}$$

However, this is a simplified formula that cannot provide the real economical visibility of RFID implementations. RFID projects are analyzed over multiple time periods, days, months or years. These time periods force companies take into account the time value of money. The following equation presents the ROI formula considering the time value of money [11].

$$\text{ROI} = (\frac{\sum_{t=1}^{n} \frac{V_t}{(1+D)^t}}{V_i} - 1) * 100 \tag{3.2}$$

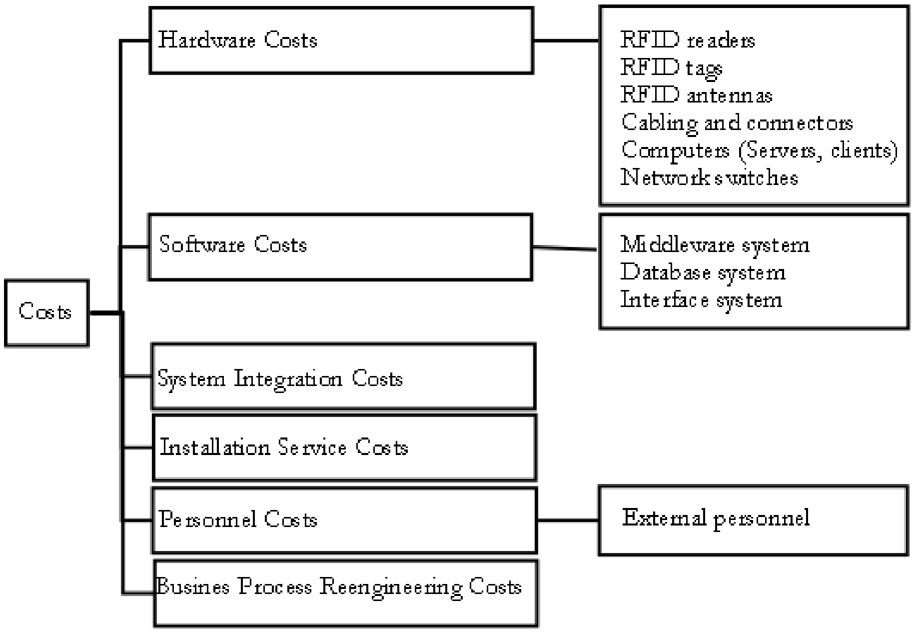


Figure 3.5: RFID implementation costs tree (Banks *et al.* [11])

Where:
V_i is the investment required by the project.
V_t is the monetary yield of the project at the end of time period t.
n is the number of periods.
t is the iterative time period.
D is the discount rate for the time value of money.

ROI analyses will be positive if the project is profitable, or it will be negative for unprofitable projects.

3.5.3 Key factors to obtain a positive ROI

Goel [55] reports that, to understand the ROI of RFID implementation, an organization must analyze the economic justification of RFID. He also concludes that they must first understand RFID technology, then understand potential uses of RFID in their environment and finally decide how to make the investment.

A positive ROI depends on the technology costs; price of tags, readers and middleware, implementation costs, maintenance service cost, etc. The level of RFID tagging is an important cost factor. Case/pallet level tagging cost is lower than item level tagging cost which can provide more benefits. Gaukler and Seifert [52] report that there is no positive ROI of item level tagging for manufacturers while a positive ROI can be attained for retailers. Tag cost is also less important in a closed loop because tags can be used many times while, in an open loop, tags are used one time [12]. In the last years, positive ROIs have been observed from closed-loop RFID implementations in manufacturing and asset management [132].

A positive ROI also depends on the benefits that RFID can provide [39]. Classical ROI analyses focus on direct benefits, while new RFID analyses are also interested in indirect benefits [93], [90]. Direct benefits of RFID technologies include increase of sales and/or decrease of lost products that can be observed and quantified. Indirect benefits consider non financial benefits such as improved customer satisfaction and shortened customer response times, etc. These improvements cannot be quantified by a direct economical calculation but they can increase direct benefits later.

Angeles [5] reports that choosing the right technology is very important for positive ROI. He writes that three factors have to be considered when choosing RFID technology; the needs of enterprises, the needs of their partners and the needs of the industry.

Deployment of RFID technologies on entire supply chains is another important factor. If all the actors of a chain share the cost of RFID, implementation becomes easier for each of them. In a recent paper, Gaukler *et al.* [53] indicate that sharing the cost of RFID between a manufacturer and retailer can maximize the total supply chain profit. For example, Wal-Mart asked its 100 largest suppliers to use RFID at the pallet and case levels in 2005. Wal-Mart shared the RFID deployment cost with their suppliers [147].

3.5.4 ROI analyses on RFID projects

ROI analyses are very important for companies to determine whether an RFID investment will repay the investor. ROI analyses on RFID projects in the literature are still limited because of the current stage of the RFID technology and because companies that conduct successful analyses want to hide their results from their competitors [11].

IBM and Accenture developed an ROI calculator [134]. This calculator focuses on a supply chain that includes manufacturer, distributor, retailer, etc. The tagging level (item, case and pallet), decrease in labor cost, reduced inventory levels, more detailed information about the firm's processes are the main subjects that they are interested in. The companies can use this calculator by changing the nature and the number of variables.

IBM Business Consulting Services conducted an “EPC Forum survey" with over

60 sponsor and non sponsor companies of the Auto-ID center. The aim of this study is to give an early indication of directions and priorities to the companies (Gramling *et al.* [56]). Procter & Gamble, Wal-Mart, Target and Johnson & Johnson are the main sponsors of this work. The participants have a wide range of functions; finance, supply chain, marketing and technology. Furthermore, the companies are from Europe, South America and the US. The majority of participants are manufacturers. This survey shows that most of the end users expect to drive attractive ROI results from case and pallet level implementation. They also write that over 70% of retailers expect to be rolling out full implementation of Auto-ID by the end of 2004; while about 50% of manufacturers expect to reach rollout at the end of 2004.

In this section, we reviewed ROI analyses of RFID deployments in supply chains. The literature on this subject is limited. RFID technologies can provide important benefits to companies. However, because of their high costs, integrating RFID technologies in companies still require important investigations. Furthermore, every company should perform its own ROI analysis, because an RFID technology can be more beneficial for a company than another technology and/or for another company environment [121].

3.6 General analyses and discussions

This section shows that RFID technologies can provide several advantages in supply chain management. The main advantages of RFID technologies in supply chains are:

- Improvement of traceability and visibility of products and processes,
- Increase of efficiency and speed of processes,
- Improvement on information accuracy,
- Reduction of inventory losses,
- Facilitation of management through real-time information.

There have been important implementations conducted by pioneer companies such as Wal-Mart, Metro, Mark and Spencer, Tesco, Gillette and Procter & Gamble. RFID applications have marked significant progress in some industries such as automobile industry, cattle ranching, healthcare, manufacturing, military, payment transactions, retailing, transportation, warehousing and distribution systems [11]. However, real applications of RFID technologies are still limited because of various technical and economical obstacles. Metal and liquid environment can disturb reading performances of RFID technologies. Numerous tests are conducted to obtain optimum technologies according to the environment. Lack of international standards is another disadvantage. For example, there are important differences between the UHF frequency in Europe and USA. Furthermore, the costs of RFID are still often much larger than the costs of current identification technologies. RFID technologies have been attractive in numerous contexts and for numerous companies, but most of them still prefer to start with pilot projects and ROI analyzes to evaluate costs and profits. However, we indicate that real RFID implementations in a complete system for several products and process, when all actors of the supply chain can provide strong collaboration and cost sharing can improve significantly performance of supply chains and thus increase benefits.

This review shows that most of the analytical and simulation models proposed in the literature are limited to one product, one retailer, one manufacturer, etc. However, conducting research for multiple items and multiple actors can provide more realist analyses of supply chains. Moreover, the vast majority of the studies in the literature consider that RFID technologies are perfect and can eliminate all errors in the supply chains. However, there are numerous different RFID systems obtained by combining different types and numbers of tags, frequencies and readers, tagging levels, open/closed loops, environment sensors. The costs and potential benefits of these technologies vary in a wide range. Although some studies take into account that RFID technologies are not perfect and their performances increase with their costs, many research opportunities still remain.

Choosing the right technology for an environment is a key decision factor for companies to gain the most out of RFID technologies. Analyzing the environment and defining their objectives, constraints, strengths, weaknesses, opportunities, and threats are as important as analyzing different RFID technologies in order to choose and implement the most efficient technology. We also highlight the importance of reengineering through RFID technologies. In this survey, we present numerous publications that show that RFID technologies improve supply chains. However, reorganizing supply chains using this new technology can significantly increase gains.

3.7 Conclusion

This survey covers potential benefits of RFID technologies in supply chains. We analyze the literature according to two criteria; the problems for which RFID can improve efficiency and the methods used to analyze the impacts of RFID technologies. Thus, we first focus on cost reduction and value creation, particularly related to inventory inaccuracy, the bullwhip effect and the replenishment policies. Then, we survey analytical models, simulations, case studies and experiments that were developed to analyze the impact of RFID technologies on supply chain management. Finally, some ROI analyzes are presented.

The originality of this section is that we present a complete review of the literature through statements and critical analyses of related publications. We also develop an effective overview of the challenges and benefits related to integrating RFID in supply chains.

In surveying the literature, we observe that there are four main limitations:

- Most of the previous research considers RFID as a perfect technology which can eliminate all inaccuracy problems in supply chains.

- We also point out that these studies are limited to provide a complete analysis of the impacts of RFID technologies on supply chains performances and economical issues. Most of the studies analyze single-level supply chains and/or on a single-period time and/or for a single type of product.

- Most of the previous studies only develop analytical models. These models do not provide a dynamic analysis, so are not capable to fully estimate the impacts of real-time information obtained by RFID technologies.

- We notice that most of the studies consider the integration of RFID technologies as replacing the current technologies with RFID technologies. Actual supply chains have been designed during long years according to the characteristics and the working issues of current technologies such as bar codes.

In this thesis, we address these gaps. We consider that RFID technologies are not perfect and it is possible to use various RFID systems which propose different efficiencies through various investments. Through analytical models and simulations, we analyze how RFID technologies effect supply chains performances in terms of customer satisfaction, inventory levels, number of transportations, etc. We also analyze how the benefits of RFID technologies can be improved in supply chains. Furthermore, we focus on economical analyses; particularly ROI (Return On Investment) analyzes, to compare the benefits obtained by RFID technologies with the costs associated to the integration of these technologies.

In the following chapter, we will investigate how RFID technologies can effect inventory management through analytical modeling. Analytic modeling is presentation of a real system through mathematical expressions according to an objective function. With analytical modeling, we will try to quantify the impacts of RFID technologies on the performance and economical issues of an inventory system.

CHAPTER 4

ANALYTICAL APPROACH: A SINGLE-LEVEL SUPPLY CHAIN

This chapter analyzes how RFID technologies can affect inventory management. We focus on a single-period inventory system in which stock-outs, and consequently lost sales, occur due to several supply chain errors such as theft, misplacements, etc. We develop two analytical models (Newsvendor model) to analyze the effects of supply chain errors and to evaluate the impacts of RFID technologies on the management of an inventory system.

Part of this chapter was presented in the international conference MOSIM 2008 [119] and [120] (will be submitted for publication in an international journal).

4.1 Introduction

Inventory management has an important role in the strategies of companies to satisfy customer demands on time. Most inventory processes are automated by using information systems to better control inventory levels. However, inventory level records often mismatch with the real physical inventory levels because of various potential supply chain errors (theft, damages, fraud, misplacements, etc.). DeHoratius and Raman [36] report that 65% of inventory records in retail stores do not match real physical inventories. This discrepancy, called inventory inaccuracy, accumulates over time because of the missing real time alignment of data and physical inventory levels. Inventory inaccuracy can deeply affect the performance of firms and can thus reduce profits because of the increase of unexpected stock-outs. Raman *et al.* [110] found in a case study that even 3.4% of misplaced products can decrease profits by 25%.

In recent years, several academic and industrial authors have focused on RFID technologies as one of the possible solutions to improve inventory management problems. These technologies have some advantages over current identification technologies (bar code). They can identify each product with a specific number for each tag, while bar code technologies can only identify the product type. They can also communicate with numerous objects at the same time and at a distance, while bar code technologies can only read one product at a time, and need a contact and direct line of sight to read the product code. RFID technologies can thus decrease inventory inaccuracies by improving product visibility in supply chains and through real-time alignments of data records of inventory levels and real physical inventories.

However, companies still hesitate to integrate RFID technologies, mainly because RFID costs are often much higher than the costs of bar code technologies. Thus, firms have to conduct cost and benefit analyses to decide on RFID integration.

In this chapter we investigate how RFID technologies can affect inventory management in which stock-outs, and consequently lost sales, occur due to several supply chain errors such as theft, misplacements, etc. We develop two analytical models (Newsvendor model) first to analyze the impacts of supply chain errors on an inventory system and then to evaluate how can RFID technologies affect this inventory system management.

This chapter is organized as follows. We present a general overview and a short state of the art of the Newsvendor model in Sections 2 and 3. Section 4 presents our modeling and the results of the analytical approach. General analyses and discussions are provided in section 5. Conclusions are discussed in the last section of this chapter.

4.2 Newsvendor model

The Newsvendor problem is an analytical model that focuses on seasonal items with short life cycles or seasonal demands. This problem is called Newsvendor problem because it is similar to a Newsvendor's daily decision to determine at the beginning of the day how many copies of a newspaper have to be bought, such that every sold copy provides a profit and every unsold copy causes a loss [32]. Thus, the main objective of this model is deciding the optimal order quantity to maximize profit.

In Newsvendor modeling, order decisions are made before the selling season. The vendor has to prevent two situations; overstock and stock-out. If the order quantity is larger than the demand quantity, all unsold goods at the end of the selling season are salvaged at a price below the selling cost. Unsatisfied demand corresponds to lost sales and there is a penalty cost for lost sales. Figure 4.1 shows over-stock and stock-out situations.

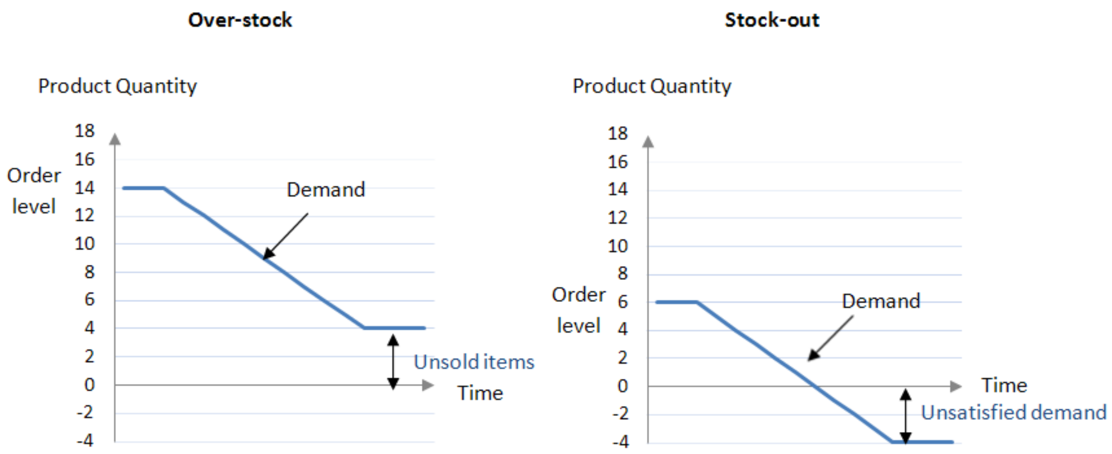


Figure 4.1: Over-stock and stock-out situations for the Newsvendor Model

The Newsvendor model can be associated to numerous real-life situations such as the Christmas season for toys, or the spring and winter seasons for the fashion and sport industries. It is mainly used in the fashion and sporting industries, both at the production and logistics levels [78]. The Newsvendor model can also be used for the advanced booking of orders in service industries such as airlines, hotels, etc [149]. The fast evolution of technologies and new requirements of competitive markets increase significantly the interest of companies in items that have short life cycles and seasonal demands in short selling seasons [47].

4.3 Literature Review

The Newsvendor model is a rather old model. It has been developed by numerous authors (Edgeworth [43] in 1888, Hertz and Schaffir [62], Hadley and Whitin [58], etc.). The classical Newsvendor model is expressed as follows:

$$Profit = \begin{cases} (C_{sell} - C_{buy})Q - C_{pen}(x - Q) & \text{if } x \geq Q \\ C_{sell}x + C_{salv}(Q - x) - C_{buy}Q & \text{else} \end{cases} \tag{4.1}$$

Where:

Q : Order quantity,
x : Demand quantity,
C_{sell} : Unit selling price,
C_{buy} : Unit cost,
C_{salv} : Unit salvage price,
C_{pen} : Unit shortage penalty cost.

Since the first studies, this model has been frequently used on different subjects. Numerous authors have developed various extensions of this model; multiple products, multiple periods, multiple actors, different objective functions, different ordering policies, different pricing and discounting strategies, etc. [78].

We focus on the studies that use Newsvendor modeling to analyze the impacts of RFID technologies on inventory inaccuracy. The papers of Sahin [116], Rekik *et al.* [111] [112] [113] [114], Uçkun *et al.* [138] [139] were reviewed in details in Chapter 2 (Literature Review of RFID Applications in Supply Chains), Section 3.4.1 (Analytical models).

In surveying the literature on the impacts of RFID on inventory inaccuracy by using the Newsvendor model, we observe that there are two main limitations in these studies. Most of the previous research focus on a single supply chain error. Moreover, RFID is considered to be a perfect technology that can eliminate all inaccuracies on inventory levels.

The originality of this study is that we integrate several supply chain errors in one model that makes it more realistic. We also consider, contrary to numerous papers in the literature, that RFID technologies are not perfect and it is possible to use various RFID systems which propose different efficiencies depending on the investment. Part of this study was presented in the international conference MOSIM 2008 [119].

4.4 Modeling and analyses of the models

In this section we compare two Newsvendor models to analyze how RFID can affect a retailer system in which inventory inaccuracy occurs. We develop two models. The first model contains several supply chain errors such as thefts, misplacements, expired products and unavailable items for sale. These errors can cause unexpected stock-outs and thus loss of potential customers. In the second model, the same problems are analyzed by integrating RFID technologies.

4.4.1 Model 1: Integration of inventory problems

This model is an extension of the classical Newsvendor model. Before the selling season, the retailer buys the products at a unit cost (C_{buy}) to sell them at a unit selling price (C_{sell}). If the quantity that is bought (Q) is not sufficient to satisfy the client demand (x), the non-satisfied demand ($x - Q$) is considered as lost sales with a unit penalty cost (C_{pen}) associated. Conversely, if the ordered quantity is larger than the demand at the end of the selling season, all unsold goods ($Q - x$) are salvaged at a unit price below the selling cost (C_{salv}).

During the selling season, customers cannot access all products because of misplaced items, thefts, expired products or unavailable items for sale. The availability rate of products is denoted by θ. The inaccessible product quantity is thus $(1 - \theta)$ percent of the ordered quantity (Q). Hence, the quantity available for sale is θQ. At the end of the selling season, misplaced items can be found and can be sold at the discounted unit price C_{salv}. The other lost products (thefts, expired products and unavailable items for sale) represent β percent of the inaccessible products and will never be sold.

The objective of this model is to find the optimal order quantity that maximizes the profit under the previous constraints.

In this model the availability rate of products (θ) and the demand (x) are considered uniformly distributed. The probability density function and the cumulative distribution function of demand and the product availability rate are given in (4.2) and (4.3).

$$\begin{aligned} f(x) &= \begin{cases} 1/(U_x - L_x) & \text{if } \ L_x \leq x \leq U_x \\ 0 & \text{else} \end{cases} \\ g(\theta) &= \begin{cases} 1/(U_\theta - L_\theta) & \text{if } \ L_\theta \leq \theta \leq U_\theta \\ 0 & \text{else} \end{cases} \end{aligned} \tag{4.2}$$

$$F(x) = \begin{cases} 0 & \text{if } \ x \leq L_x \\ (x - L_x)/(U_x - L_x) & \text{else if } \ L_x \leq x \leq U_x \\ 1 & \text{else} \end{cases} \tag{4.3}$$

The notations used in this section are shown in Table 4.1.

Q	:	Order quantity	$1-\beta$	:	Misplacement rate
$\pi(Q)$	:	Expected profit	$\mu_{...}$	:	Mean of ...
C_{sell}	:	Unit selling price	$\sigma_{...}$	:	Standard deviation of ...
C_{buy}	:	Unit buying cost	$U_{...}$	:	Upper bound of ...
C_{salv}	:	Unit salvage value	$L_{...}$	:	Lower bound of ...
C_{pen}	:	Unit shortage penalty cost	f, g	:	Probability density function
x	:	Demand Quantity	F	:	Cumulative distribution function
θ	:	Availability rate			

Table 4.1: Notations

4.4.2 Analyses and results of Model 1

We can express the profit through several possible incomes and costs; such as the income in the selling season, the income through the salvaged products at the end of the season, the shortage penalty cost and buying cost. The profit function can be expressed as in (4.4).

$$\begin{aligned} \text{Profit} &= C_{sell} \min(x, \theta Q) + C_{salv}\Big(Q - \beta(1-\theta)Q - \min(x, \theta Q)\Big) \\ &- C_{pen} \max(x - \theta Q, 0) - C_{buy} Q \end{aligned} \tag{4.4}$$

We can redefine the profit as follows:

$$
\begin{aligned}
\text{Profit} &= C_{sell}x \\
&+ C_{salv}\max(\theta Q - x, 0) \\
&+ C_{salv}Q(1-\theta)(1-\beta) \\
&- (C_{sell} + C_{pen})\max(x - \theta Q, 0) \\
&- C_{buy}Q
\end{aligned} \tag{4.5}
$$

The profit function (4.5) is composed of five parts.

1. $(C_{sell}x)$ is the income through sales.
2. $(C_{salv}Max(\theta Q - x, 0))$ is the income obtained by salvaging the remaining products at the end of the season.
3. $(C_{salv}Q(1-\theta)(1-\beta))$ is the income obtained by salvaging the misplaced items that are found at the end of the season.
4. $((C_{sell} + C_{pen})Max(x - \theta Q, 0))$ is the lost sales because of stock-outs.
5. (CQ) is the cost of buying the products.

Using profit function (4.5), the expected profit is:

$$
\begin{aligned}
\pi(Q) &= C_{sell}\mu_x + (C_{salv} - C_{buy})Q - C_{salv}Q(\mu_\beta + \mu_\theta - \mu_\theta\mu_\beta) \\
&- (C_{sell} + C_{pen}) \int_{\theta=L_\theta}^{U_\theta} \int_{x=\theta Q}^{\infty} (x - \theta Q) f(x) g(\theta) dx d\theta \\
&+ C_{salv} \int_{\theta=L_\theta}^{U_\theta} \int_{x=0}^{\theta Q} (\theta Q - x) f(x) g(\theta) dx d\theta \\
&= C_{sell}\mu_x + (C_{salv} - C_{buy})Q - C_{salv}Q(\mu_\beta + \mu_\theta - \mu_\theta\mu_\beta)
\end{aligned}
$$

$$
\begin{aligned}
& - \quad (C_{sell} + C_{pen}) \int_{\theta=L_\theta}^{U_\theta} \int_{x=\theta Q}^{\infty} x f(x) g(\theta) dx d\theta \\
& + \quad (C_{sell} + C_{pen}) \int_{\theta=L_\theta}^{U_\theta} \int_{x=\theta Q}^{\infty} \theta Q f(x) g(\theta) dx d\theta \\
& + \quad C_{salv} \int_{\theta=L_\theta}^{U_\theta} \int_{x=0}^{\theta Q} \theta Q f(x) g(\theta) dx d\theta - C_{salv} \int_{\theta=L_\theta}^{U_\theta} \int_{x=0}^{\theta Q} x f(x) g(\theta) dx d\theta
\end{aligned}
$$

$$
\begin{aligned}
& = \quad C_{sell}\mu_x + (C_{salv} - C_{buy})Q - C_{salv}Q(\mu_\beta + \mu_\theta - \mu_\theta\mu_\beta) \\
& - \quad (C_{sell} + C_{pen}) \int_{\theta=L_\theta}^{U_\theta} \int_{x=0}^{\infty} x f(x) g(\theta) dx d\theta \\
& + \quad (C_{sell} + C_{pen}) \int_{\theta=L_\theta}^{U_\theta} \int_{x=0}^{\theta Q} x f(x) g(\theta) dx d\theta \\
& + \quad (C_{sell} + C_{pen}) \int_{\theta=L_\theta}^{U_\theta} \int_{x=-\infty}^{\infty} \theta Q f(x) g(\theta) dx d\theta \\
& - \quad (C_{sell} + C_{pen}) \int_{\theta=L_\theta}^{U_\theta} \int_{x=-\infty}^{\theta Q} \theta Q f(x) g(\theta) dx d\theta \\
& + \quad C_{salv} \int_{\theta=L_\theta}^{U_\theta} \int_{x=-\infty}^{\theta Q} \theta Q f(x) g(\theta) dx d\theta - C_{salv} \int_{\theta=L_\theta}^{U_\theta} \int_{x=-\infty}^{0} \theta Q f(x) g(\theta) dx d\theta \\
& - \quad C_{salv} \int_{\theta=L_\theta}^{U_\theta} \int_{x=0}^{\theta Q} x f(x) g(\theta) dx d\theta
\end{aligned} \tag{4.6}
$$

By using the characteristics of the probability density functions (4.2) and the cumulative distribution function (4.3), the expected profit can be expressed as follows:

$$
\begin{aligned}
\pi(Q) &= C_{sell}\mu_x + (C_{salv} - C_{buy})Q - C_{salv}Q(\mu_\beta + \mu_\theta - \mu_\theta\mu_\beta) \\
&- (C_{sell} + C_{pen}) \int\limits_{\theta=L_\theta}^{U_\theta} \int\limits_{x=L_x}^{U_x} xf(x)g(\theta)dxd\theta \\
&+ (C_{sell} + C_{pen} - C_{salv}) \int\limits_{\theta=L_\theta}^{U_\theta} \int\limits_{x=0}^{\theta Q} xf(x)g(\theta)dxd\theta \\
&+ (C_{sell} + C_{pen})Q \int\limits_{\theta=L_\theta}^{U_\theta} \theta g(\theta)d\theta \\
&- (C_{sell} + C_{pen} - C_{salv})Q \int\limits_{\theta=L_\theta}^{U_\theta} \theta F(\theta Q)g(\theta)d\theta \\
&+ C_{salv}Q \int\limits_{\theta=L_\theta}^{U_\theta} \int\limits_{x=L_x}^{U_x} \theta f(x)g(\theta)dxd\theta
\end{aligned}
$$

$$
\begin{aligned}
&= C_{sell}\mu_x - (C_{sell} + C_{pen})\mu_x + C_{salv}Q\mu_\theta + (C_{salv} - C_{buy})Q \\
&- C_{salv}Q(\mu_\beta + \mu_\theta - \mu_\theta\mu_\beta) \\
&+ (C_{sell} + C_{pen} - C_{salv}) \int\limits_{\theta=L_\theta}^{U_\theta} \int\limits_{x=0}^{\theta Q} xf(x)g(\theta)dxd\theta + (C_{sell} + C_{pen})Q\mu_\theta \\
&- (C_{sell} + C_{pen} - C_{salv})Q \int\limits_{\theta=L_\theta}^{U_\theta} \theta F(\theta Q)g(\theta)d\theta
\end{aligned}
$$

$$
\begin{aligned}
&= -C_{pen}\mu_x + (C_{salv} - C_{buy})Q - C_{salv}Q(\mu_\beta - \mu_\theta\mu_\beta) + (C_{sell} + C_{pen})\mu_\theta Q \\
&+ (C_{sell} + C_{pen} - C_{salv}) \int\limits_{\theta=L_\theta}^{U_\theta} \int\limits_{x=0}^{\theta Q} xf(x)g(\theta)dxd\theta
\end{aligned}
$$

$$- \quad (C_{sell} + C_{pen} - C_{salv})Q \int_{\theta=L_\theta}^{U_\theta} \theta F(\theta Q) g(\theta) d\theta \tag{4.7}$$

We observe that the profit function (4.7) depends on the relation between the available products (θQ) and the demand (x).

We consider that:

$$\begin{cases} L_{\theta Q} = L_x + e_1, & \forall e_1 \in \Re \\ U_{\theta Q} = U_x + e_2, & \forall e_2 \in \Re \end{cases} \tag{4.8}$$

In order to evaluate the impact of errors on profit, we analyze two cases:

1. Deterministic case: The error is assumed to be deterministic ($\sigma_\theta = 0$) enabling to study the impact of μ_θ on the profit.
2. Stochastic case: The error is assumed to be uniformly distributed to evaluate the impact of σ_θ on the profit.

4.4.2.1 Deterministic case

The deterministic case corresponds to:

$$\begin{cases} \sigma_\theta = 0 \\ \theta = \mu_\theta \end{cases} \tag{4.9}$$

We first focus on the case where e_1 and e_2 are equal to 0 in (4.8). By using (4.9), we can write that:

$$\begin{cases} \theta = \mu_\theta \\ L_{\mu_\theta Q} = L_x \\ U_{\mu_\theta Q} = U_x \end{cases} \tag{4.10}$$

Therefore, the expressions of the expected profit (4.7) can be written as shown below.

$$\mu_\theta F(\mu_\theta Q) = \begin{cases} 0 & \text{if } \mu_\theta Q \leq L_x \\ \dfrac{Q\mu_\theta^2 - L_x\mu_\theta}{U_x - L_x} & \text{else if } L_x \leq \mu_\theta Q \leq U_x \\ \mu_\theta & \text{else} \end{cases} \tag{4.11}$$

$$\int\limits_{x=0}^{\mu_\theta Q} x f(x)dx = \begin{cases} 0 & \text{if } \mu_\theta Q \leq L_x \\ \dfrac{Q^2\mu_\theta^2 - L_x^2}{2(U_x - L_x)} & \text{else if } L_x \leq \mu_\theta Q \leq U_x \\ \mu_x & \text{else} \end{cases} \tag{4.12}$$

These parts for other cases of e_1 and e_2 are provided in Table 4.2. Through these derivatives, we can redefine the expected profit for the deterministic case for all values of $\mu_\theta Q$.

We can redefine the expected profit for the deterministic case for the different values of $(\mu_{\theta Q})$ when e_1 and e_2 are equal to 0 as follows:

$$\pi(Q) = \begin{cases} -C_{pen}\mu_x + Q\big((C_{sell} + C_{pen})\mu_\theta \\ +C_{salv}(1 - \mu_\beta + \mu_\theta\mu_\beta) - C_{buy}\big) & \text{if } \mu_\theta Q \leq L_x \\ \\ -C_{pen}\mu_x + Q\big((C_{sell} + C_{pen})\mu_\theta \\ +C_{salv}(1 - \mu_\beta + \mu_\theta\mu_\beta) - C_{buy}\big) & \text{else if } L_x \leq \mu_\theta Q \leq U_x \\ \\ -C_{pen}\mu_x + Q(C_{sell} + C_{pen})\mu_\theta \\ +Q\big(C_{salv}(1 - \mu_\beta + \mu_\theta\mu_\beta) - C_{buy}\big) \\ +(C_{sell} + C_{pen} - C_{salv})(\mu_x - Q\mu_\theta) & \text{else} \end{cases} \tag{4.18}$$

Through (4.18), we observe that the profit depends on the order quantity, demand quantity, product costs, rate of errors and the relation between product availability and demand.

We illustrate the evolution of the profit with the order quantity in Figure 4.2. The parameters used in this figure are: C_{sell}=20 €, C_{buy}=10 €, C_{salv}=10 €, C_{pen}=10

Condition 1	Condition 2	$\mu_\theta F(\mu_\theta Q)$	$\int_{x=0}^{\mu_\theta Q} xf(x)dx$
$e_1 \geq 0,\, e_2 \geq 0$	$\mu_\theta Q \leq L_x$	0	0
	$L_x \leq \mu_\theta Q \leq L_x + e_1$	0	$\frac{Q^2\mu_\theta^2 - L_x^2}{2(U_x - L_x)}$ (4.13)
	$L_x + e_1 \leq \mu_\theta Q \leq U_x$	$\frac{Q\mu_\theta^2 - (L_x + e_1)\mu_\theta}{(U_x + e_2) - (L_x + e_1)}$ (4.14)	(4.13)
	$U_x \leq \mu_\theta Q \leq U_x + e_2$	(4.14)	μ_x
	$U_x + e_2 \leq \mu_\theta Q$	μ_θ	μ_x
$e_1 \leq 0,\, e_2 \leq 0$	$\mu_\theta Q \leq L_x - e_1$	0	0
	$L_x - e_1 \leq \mu_\theta Q \leq L_x$	$\frac{Q\mu_\theta^2 - (L_x - e_1)\mu_\theta}{(U_x - e_2) - (L_x - e_1)}$ (4.15)	0
	$L_x \leq \mu_\theta Q \leq U_x - e_2$	(4.15)	(4.13)
	$U_x - e_2 \leq \mu_\theta Q \leq U_x$	μ_θ	(4.13)
	$U_x \leq \mu_\theta Q$	μ_θ	μ_x
$e_1 \geq 0,\, e_2 \leq 0$	$\mu_\theta Q \leq L_x$	0	0
	$L_x \leq \mu_\theta Q \leq L_x + e_1$	0	(4.13)
	$L_x + e_1 \leq \mu_\theta Q \leq U_x - e_2$	$\frac{Q\mu_\theta^2 - (L_x + e_1)\mu_\theta}{(U_x - e_2) - (L_x + e_1)}$ (4.16)	(4.13)
	$U_x - e_2 \leq \mu_\theta Q \leq U_x$	μ_θ	(4.13)
	$U_x \leq \mu_\theta Q$	μ_θ	μ_x
$e_1 \leq 0,\, e_2 \leq 0$	$\mu_\theta Q \leq L_x - e_1$	0	0
	$L_x - e_1 \leq \mu_\theta Q \leq L_x$	$\frac{Q\mu_\theta^2 - (L_x - e_1)\mu_\theta}{(U_x - e_2) - (L_x - e_1)}$ (4.17)	0
	$L_x \leq \mu_\theta Q \leq U_x$	(4.17)	(4.13)
	$U_x \leq \mu_\theta Q \leq U_x + e_2$	(4.17)	(4.13)
	$U_x + e_2 \leq \mu_\theta Q$	μ_θ	μ_x

Table 4.2: Other cases when product availability is deterministic

€, μ_x=400, L_x=0, U_x=800, μ_θ=0.6 and μ_β=0.5.

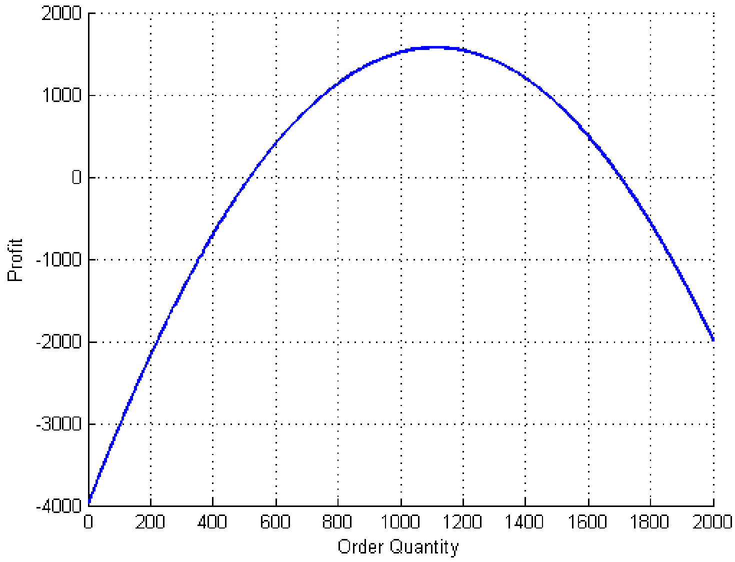


Figure 4.2: Profit over order quantity: There is an optimal order quantity that maximizes the profit.

Figure 4.2 illustrates the fact that the profit increases when the order quantity increases up to a critical value. The vendor cannot satisfy all the demand if he orders a very small quantity. The vendor is penalized because of the penalty cost due to unsatisfied customer demands. For values larger than this critical value, the profit of the vendor decreases because of over-stocks. At the end of the season, all unsold products will be sold below their unit buying cost. The critical value that maximizes profit is called the optimal order quantity (Q^*).

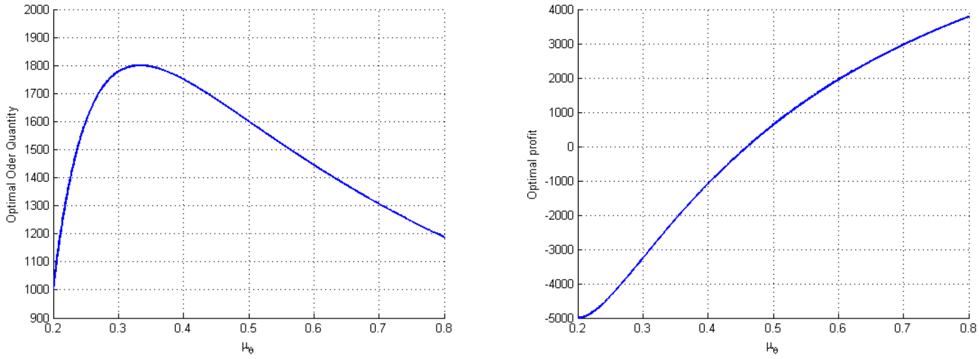
We can find the optimal order quantity Q^* which maximizes the profit in (4.18). The order quantity is optimal if the number of available products is between the lower and upper bounds of the demand ($L_x \leq \mu_\theta Q \leq U_x$), (the function $\pi(Q)$ is concave for the values of $\mu_\theta Q$ when $L_x \leq \mu_\theta Q \leq U_x$). Recall that a function f twice differentiable is strictly concave if $f'' < 0$. There is thus a value of Q which maximizes the expected profit function $\pi(Q)$ (4.18). This quantity corresponds to the point where the derivative of the function $\pi(Q)$ is equal to zero ($\pi'(Q^*) = 0$). By differentiating $\pi(Q)$ for the values of $\mu_\theta Q$ when $L_x \leq \mu_\theta Q \leq U_x$, we find:

$$\pi'(Q) = \begin{cases} (C_{sell} + C_{pen})\mu_\theta + C_{salv}(1 - \mu_\beta + \mu_\theta\mu_\beta) - C_{buy} \\ -(C_{sell} + C_{pen} - C_{salv})\dfrac{2Q\mu_\theta^2 - 2L_x\mu_\theta}{2(U_x - L_x)} \end{cases} \tag{4.19}$$

The value which makes the derivative of the profit function equal zero ($\pi'(Q^*) = 0$), is the optimal order quantity Q^*, which can be written as follows:

$$Q^* = \frac{((C_{sell} + C_{pen})\mu_\theta + C_{salv}(1 - \mu_\beta + \mu_\theta\mu_\beta) - C_{buy})(U_x - L_x)}{(C_{sell} + C_{pen} - C_{salv})\mu_\theta} + L_x \tag{4.20}$$

The expression (4.20) shows that the optimal order quantity Q^* depends on the demand quantity, product costs and supply chain errors. We illustrate the variation of the optimal order quantity (Q^*) with the mean of availability rate in Figure 4.3a with the following parameters: C_{sell}=20 €, C_{buy}=10 €, C_{salv}=10 €, C_{pen}=10 €, μ_x=400, L_x=0, U_x=800 and μ_β=0.5.



(a) Optimal order quantity (Q^*)

(b) Optimal profit ($\pi(Q^*)$)

Figure 4.3: Optimal order quantity (Q^*) versus optimal profit ($\pi(Q^*)$): Deterministic case

Figure 4.3a shows that there is a threshold value (μ_θ^t) of the product availability rate (μ_θ) for which Q^* is maximal. For availability rates below this value, increasing μ_θ also increases the optimal order quantity. For very small values of μ_θ, more products have to be ordered to prevent stock-outs and consequently the penalty cost. On the other hand, for product availability rates above μ_θ^t, increasing μ_θ reduces the optimal order quantity (Q^*). Through the increase of the product availability rate, customers can access more products. The vendor can thus maximize the profit by ordering fewer products.

We can also find the optimal profit function for the optimal oder quantity Q^* given in (4.20) when $L_x \leq \mu_\theta Q \leq U_x$.

$$\pi(Q^*) = \begin{cases} -C_{pen}\mu_x + Q^*\big((C_{sell} + C_{pen})\mu_\theta + C_{salv}(1 - \mu_\beta + \mu_\theta\mu_\beta) - C_{buy}\big) \\ -(C_{sell} + C_{pen} - C_{salv})\big(\dfrac{(Q^*)^2\mu_\theta^2 - 2L_x\mu_\theta Q^* - L_x^2}{2(U_x - L_x)}\big) \end{cases} \tag{4.21}$$

The optimal profit depends on the optimal order quantity, demand quantity, product costs and supply chain errors. We illustrate the variation of the optimal profit quantity with the mean of the availability rate in Figure 4.3b. The parameters used in this figure are the same than for Figure 4.3a.

Figure 4.3b shows that the availability rate increases the optimal profit. We also observe that, when the availability rate is larger than a critical value, the profit can increase even if the vendor orders less products.

Through Figure 4.3, we observe that if product availability is increased by 10% (μ_θ increases from 0.6 to 0.7), the profit increases by 50% with an optimal order quantity reduced only by 11%.

4.4.2.2 Stochastic case

As mentioned before, we consider that:

$$\begin{cases} L_\theta Q = L_x + e_1 \\ U_\theta Q = U_x + e_2 \end{cases} \tag{4.22}$$

We first focus on the case where e_1 and e_2 are equal to 0. Other cases for e_1 and e_2 are shown in Table 4.3. Through the derivatives given in Table 4.3, we can redefine the expected profit for the stochastic case for all possible values of $\mu_\theta Q$.

$$\int_{L_\theta}^{U_\theta} \theta F(\theta Q) g(\theta) d\theta = \begin{cases} 0 & \text{if } \theta Q \leq L_x \\ \dfrac{Q(\mu_\theta^2 + \sigma_\theta^2) - L_x \mu_\theta}{U_x - L_x} & \text{else if } L_x \leq \theta Q \leq U_x \\ \mu_\theta & \text{else} \end{cases} \tag{4.23}$$

$$\int_{\theta=L_\theta}^{U_\theta} \int_{x=0}^{\theta Q} x f(x) g(\theta) dx d\theta = \begin{cases} 0 & \text{if } \theta Q \leq L_x \\ \dfrac{Q^2(\mu_\theta^2 + \sigma_\theta^2) - L_x^2}{2(U_x - L_x)} & \text{else if } L_x \leq \theta Q \leq U_x \\ \mu_x & \text{else} \end{cases} \tag{4.24}$$

We can redefine the expected profit for the stochastic case when e_1 and e_2 are equal to 0 as follows:

$$\pi(Q) = \begin{cases} -C_{pen}\mu_x + Q(C_{sell} + C_{pen})\mu_\theta & \\ +Q\big(C_{salv}(1 - \mu_\beta + \mu_\theta \mu_\beta) - C_{buy}\big) & \text{if } \theta Q \leq L_x \\ & \\ -C_{pen}\mu_x + Q(C_{sell} + C_{pen})\mu_\theta & \\ +Q\big(C_{salv}(1 - \mu_\beta + \mu_\theta \mu_\beta) - C_{buy}\big) & \\ -(C_{sell} + C_{pen} - C_{salv})\dfrac{Q^2(\mu_\theta^2 + \sigma_\theta^2)}{2(U_x - L_x)} & \text{else if } L_x \leq \theta Q \leq U_x \\ +(C_{sell} + C_{pen} - C_{salv})\dfrac{2L_x\mu_\theta Q + L_x^2}{2(U_x - L_x)} & \\ & \\ -C_{pen}\mu_x + Q(C_{sell} + C_{pen})\mu_\theta & \\ +Q\big(C_{salv}(1 - \mu_\beta + \mu_\theta \mu_\beta) - C_{buy}\big) & \\ +(C_{sell} + C_{pen} - C_{salv})(\mu_x - Q\mu_\theta) & \text{else} \end{cases} \tag{4.30}$$

We can find the optimal profit when the number of available products (θQ) is

Condition 1	Condition 2	$\int\limits_{L_\theta}^{U_\theta} \theta F(\theta Q) g(\theta) d\theta$	$\int\limits_{\theta=L_\theta}^{U_\theta} \int\limits_{x=0}^{\theta Q} x f(x) g(\theta) dx d\theta$
$e_1 \geq 0,\ e_2 \geq 0$	$\theta Q \leq L_x$	0	0
	$L_x \leq \theta Q \leq L_x$+$e_1$	0	$\frac{Q^2(\mu_\theta^2+\sigma_\theta^2)-L_x^2}{2(U_x-L_x)}$(4.25)
	L_x+$e_1 \leq \theta Q \leq U_x$	$\frac{Q(\mu_\theta^2+\sigma_\theta^2)-(L_x+e_1)\mu_\theta}{(U_x+e_2)-(L_x+e_1)}$ (4.26)	(4.25)
	$U_x \leq \theta Q \leq U_x$+$e_2$	(4.26)	μ_x
	U_x+$e_2 \leq \theta Q$	μ_θ	μ_x
$e_1 \leq 0,\ e_2 \leq 0$	$\theta Q \leq L_x$-e_1	0	0
	L_x-$e_1 \leq \theta Q \leq L_x$	$\frac{Q(\mu_\theta^2+\sigma_\theta^2)-(L_x-e_1)\mu_\theta}{(U_x-e_2)-(L_x-e_1)}$ (4.27)	0
	$L_x \leq \theta Q \leq U_x$-$e_2$	(4.27)	(4.25)
	U_x-$e_2 \leq \theta Q \leq U_x$	μ_θ	(4.25)
	$U_x \leq \theta Q$	μ_θ	μ_x
$e_1 \geq 0,\ e_2 \leq 0$	$\theta Q \leq L_x$	0	0
	$L_x \leq \theta Q \leq L_x$+$e_1$	0	(4.25)
	L_x+$e_1 \leq \theta Q \leq U_x$-$e_2$	$\frac{Q(\mu_\theta^2+\sigma_\theta^2)-(L_x+e_1)\mu_\theta}{(U_x-e_2)-(L_x+e_1)}$ (4.28)	(4.25)
	U_x-$e_2 \leq \theta Q \leq U_x$	μ_θ	(4.25)
	$U_x \leq \theta Q$	μ_θ	μ_x
$e_1 \leq 0,\ e_2 \leq 0$	$\theta Q \leq L_x$-e_1	0	0
	L_x-$e_1 \leq \theta Q \leq L_x$	$\frac{Q(\mu_\theta^2+\sigma_\theta^2)-(L_x-e_1)\mu_\theta}{(U_x-e_2)-(L_x-e_1)}$ (4.29)	0
	$L_x \leq \theta Q \leq U_x$	(4.29)	(4.25)
	$U_x \leq \theta Q \leq U_x$+$e_2$	(4.29)	(4.25)
	U_x+$e_2 \leq \theta Q$	μ_θ	μ_x

Table 4.3: Other cases when product availability is stochastic

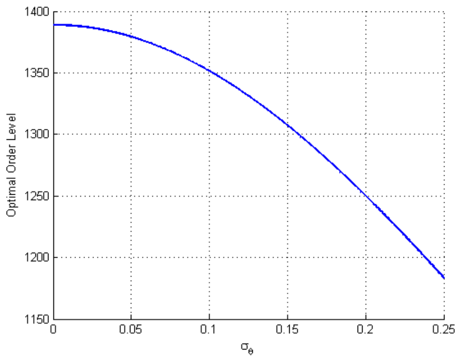
between L_x and U_x:

$$\pi(Q^*) = \begin{cases} -C_{pen}\mu_x + Q^*\big((C_{sell} + C_{pen})\mu_\theta + C_{salv}(1 - \mu_\beta + \mu_\theta\mu_\beta) - C_{buy}\big) \\ -(C_{sell} + C_{pen} - C_{salv})\big(\dfrac{(Q^*)^2(\mu_\theta^2 + \sigma_\theta^2) - 2L_x\mu_\theta Q^* - L_x^2}{2(U_x - L_x)}\big) \end{cases} \tag{4.31}$$

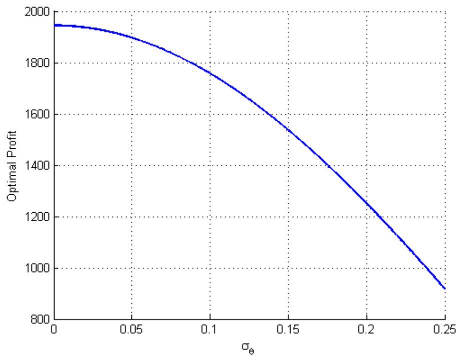
Where

$$Q^* = \Big\{ \frac{((C_{sell} + C_{pen})\mu_\theta + C_{salv}(1 - \mu_\beta + \mu_\theta\mu_\beta) - C_{buy})(U_x - L_x)}{(C_{sell} + C_{pen} - C_{salv})(\mu_\theta^2 + \sigma_\theta^2)} + \frac{L_x\mu_\theta}{\mu_\theta^2 + \sigma_\theta^2} \tag{4.32}$$

The optimal order quantity Q^* depends on the demand quantity, product costs and supply chain errors, and the optimal profit depends on the optimal order quantity, demand quantity, product costs and supply chain errors. Figure 4.4 represents the variation of the optimal order quantity and the optimal profit with the standard deviation of the availability rate. The parameters used in this figure are: C_{sell}=20 €, C_{buy}=10 €, C_{salv}=10 €, C_{pen}=10 €, μ_x=400, L_x=0, U_x=800, μ_θ=0.6 and μ_β=0.5 (i.e. the same than Figure 4.3 with μ_θ=0.6).



(a) Optimal order quantity (Q^*)



(b) Optimal profit ($\pi(Q^*)$)

Figure 4.4: Optimal order quantity versus optimal profit: Stochastic case

Figure 4.4 shows that the increase of the standard deviation of the availability rate decreases the optimal order quantity and the optimal profit. The increase of the standard deviation of the availability rate makes the systems unstable and thus difficult to manage.

Figure 4.4 shows that, when the standard deviation of the product availability (σ_θ) is reduced by 50% (σ_θ decreases from 0.2 to 0.1), the profit increases by 40%.

4.4.3 Model 2: Integration of RFID technologies

In this section, RFID technologies are integrated to Model 1 to analyze the impacts of RFID implementations on inventory inaccuracy.

As mentioned before, through radio waves, RFID technologies provide contactless real-time communication with numerous objects. This advanced communication characteristics of RFID technologies can decrease inventory errors considerably. In fact, RFID technologies can decrease the percentage of misplaced items as well as thefts. Furthermore, even if these errors occur, RFID can quickly detect them as well as expired and damaged products. RFID can improve product visibility, and thus increase the product availability rate.

However, RFID technologies are not perfect. Their overall efficiency depends on various parameters; the frequency, the tag (active or passive), the efficiency, quality and position of the antenna, the packaging of the tag, etc. The reading distance of active tags is larger than the one of passive tags. But active tags are more expensive than passive tags. The reading distance also depends on the frequency of the RFID system. Inventory management can significantly be improved through item level identification instead of case or pallet level identification.

There are also some technical obstacles. Some frequencies have reading difficulties in metal and liquid environments. For example, HF (High Frequency) penetrates water better than UHF (Ultra High Frequency) and microwave signals because high frequency signals are more absorbed by liquids [84]. The signals in high frequency bands are also affected by metal environment because metal is an electromagnetic reflector and thus reflects high frequency signals more than lower frequencies. In order to prevent these difficulties, specific solutions are developed that lead to additional costs, thus increasing the technology price.

The costs of RFID technologies depend on the identification level, the frequency, the tag type, as well as the antennas. These characteristics affect the efficiency of RFID technologies. By observing the RFID market, industrial applications and academic literature, we can assume that, when the efficiency of RFID technologies increases, the associated cost also increases. There is a relationship between the efficiency of RFID technologies (that decreases inventory errors in our model) and RFID technology unit costs. In our study we consider that, when RFID technologies are integrated, the product availability increases with the unit cost of RFID technology.

In this section, we are interested in the stochastic case of the product availability rate and demand. We consider that RFID technologies can reduce the supply chain errors by decreasing the mean and the variability of these errors. The observation of different industrial applications shows that even simple RFID systems can increase the product availability considerably. However, from a certain value of the product availability, RFID technologies only increase the product availability very slowly and the product availability converges to 1. We assume the following functions to model product availability with RFID costs. We suppose that the unit cost of RFID technology includes the tag price and other components of RFID systems as well as the middleware. The product availability can vary differently due to the parameters used in these functions.

$$\begin{cases} \mu_{\theta_{RFID}} = \mu_\theta + (a_1 - \frac{b_1}{c_1 * C_{RFID} + d_1 * \exp(C_{RFID})}) \\ \sigma_{\theta_{RFID}} = \sigma_\theta - (a_2 - \frac{b_2}{c_2 * C_{RFID} + d_2 * \exp(C_{RFID})}) \end{cases} \quad (4.33)$$

Where;

$\mu_{\theta_{RFID}}$: Mean of availability rate with RFID,

$\sigma_{\theta_{RFID}}$: Standard deviation of availability rate with RFID,

C_{RFID}: RFID unit cost.

Figure 4.5 presents different cases of the variation of the mean and the standard deviation of the product availability rate by the unit cost of RFID technologies in Euros.

We determine the parameters of (4.33) ($a1$, $b1$, $c1$, etc). The curves in the figure 4.5 can vary according to the parameters that are used. In Figure 4.5, we consider that $a_1 = 0.4$, $b_1 = 0.8$, $c_1 = 40$, $d_1 = 2$ (for Case 1), $a_2 = 0.35$, $b_2 = 0.8$, $c_2 = 80$, $d_2 = 2$ (for Case 2) and $a_2 = 0.2$, $b_2 = 0.4$, $c_2 = 40$, $d_2 = 2$ (for Case 3) and $a_2 = 0.23$, $b_2 = 0.4$, $c_2 = 40$, $d_2 = 2$ (for Case 4).

4.4.4 Analyses and results of Model 2

We integrate RFID technologies to the system. The product availability rate ($\mu_{\theta_{RFID}}$, $\sigma_{\theta_{RFID}}$) change as in (4.33). By replacing these values in the profit function (4.32), we obtain the following optimal order quantity and optimal profit for the stochastic case:

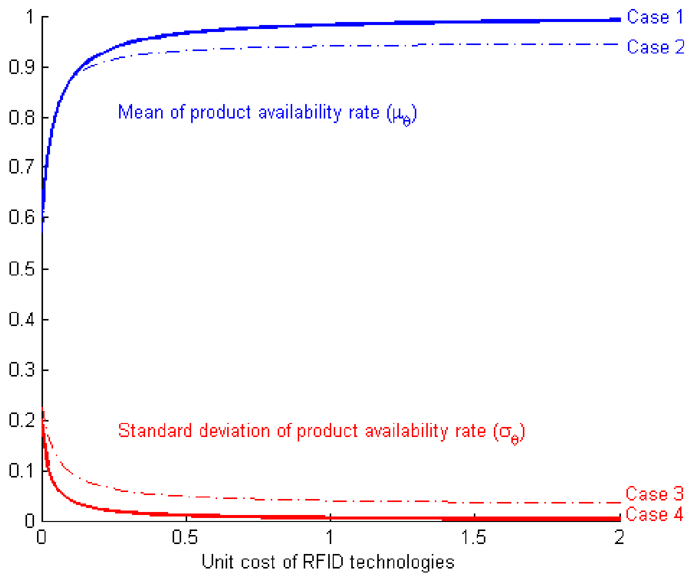


Figure 4.5: Product availability rate over unit cost of RFID

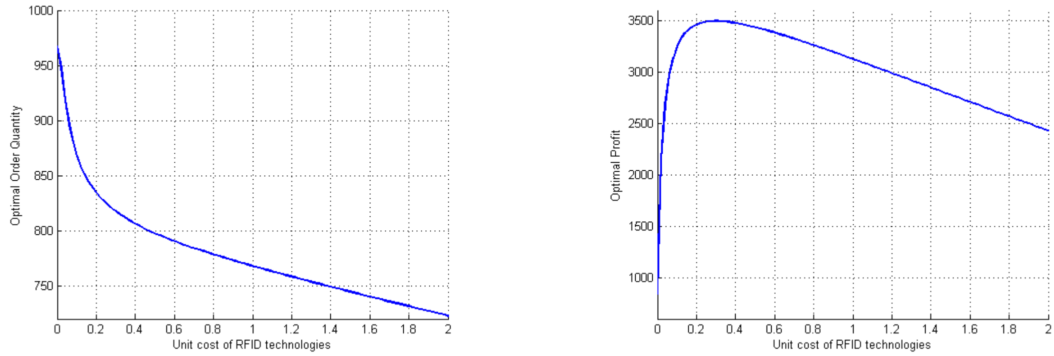
$$\pi(Q^*) = \begin{cases} -C_{pen}\mu_x + Q^*\big((C_{sell}+C_{pen})\mu_{\theta_{RFID}} - (C_{buy}+C_{RFID})\big) \\ -(C_{sell}+C_{pen}-C_{salv})\dfrac{(Q^*)^2(\mu^2_{\theta_{RFID}}+\sigma^2_{\theta_{RFID}}) - 2L_x\mu_{\theta_{RFID}}Q^* - L_x^2}{2(U_x-L_x)} \\ +Q^*C_{salv}(1-\mu_{\beta_{RFID}}+\mu_{\theta_{RFID}}\mu_{\beta_{RFID}}) \end{cases} \tag{4.34}$$

Where:

$$Q^* = \begin{cases} \dfrac{((C_{sell}+C_{pen})\mu_{\theta_{RFID}} - (C_{buy}+C_{RFID}))(U_x-L_x)}{(C_{sell}+C_{pen}-C_{salv})(\mu^2_{\theta_{RFID}}+\sigma^2_{\theta_{RFID}})} \\ +\dfrac{C_{salv}(1-\mu_{\beta_{RFID}}+\mu_{\theta_{RFID}}\mu_{\beta_{RFID}})(U_x-L_x)}{(C_{sell}+C_{pen}-C_{salv})(\mu^2_{\theta_{RFID}}+\sigma^2_{\theta_{RFID}})} + \dfrac{L_x\mu_{\theta_{RFID}}}{\mu^2_{\theta_{RFID}}+\sigma^2_{\theta_{RFID}}} \end{cases} \tag{4.35}$$

We focus on a system in which the mean and the standard deviation of product availability rate (μ_θ, σ_θ) are respectively 0.6 and 0.23. We integrate different RFID technologies to this system. In Figure 4.6a, we illustrate the variation of the optimal order quantity (Q^*) with the RFID unit cost. The parameters used in Figure 4.6a and 4.6b are: C_{sell}=20 €, C_{buy}=10 €, C_{salv}=10 €, C_{pen}=10 €, μ_x=400, L_x=0,

U_x=800 and μ_β=0.5.



(a) Optimal order quantity (Q^*)

(b) Optimal profit ($\pi(Q^*)$)

Figure 4.6: Optimal order quantity versus profit: RFID implementation

Figure 4.6a shows that the optimal order quantity that maximizes the profit decreases with the increase of the unit RFID cost. Total RFID costs increase when increasing the order quantity. Thus, vendors order less to increase the total profit.

Figure 4.6b shows the variation of the optimal profit with the unit cost of RFID technologies. By observing Figure 4.6b, we remark that the profit increases considerably up to a specific point (about 0.28 €), and then it starts to decrease. Indeed, the cost of the technology becomes larger than the income through the technology. The profit is thus optimal for a certain RFID cost. In this case, the optimal cost of RFID is closed to 0.3 €. This cost can vary with the product costs and the demand of the products.

4.5 General analyses and discussions

In this chapter, we focused on a simple inventory system to analyze how RFID technologies affect inventory management. We first developed a single period model to analyze the impacts of supply chain errors on a retailer inventory system. Our analyses show that several factors affect ordering decisions and also the total profit of the system. The main factors for the optimal order quantity and profit are product properties, supply chain error rates and customer demands.

Figure 4.7 illustrates that how product costs (salvage and penalty) can affect the optimal profit. The parameters used in this figure are: C_{sell}=20 €, C_{buy}=10 €,

μ_x=400, L_x=0, U_x=800 and μ_β=0.5.

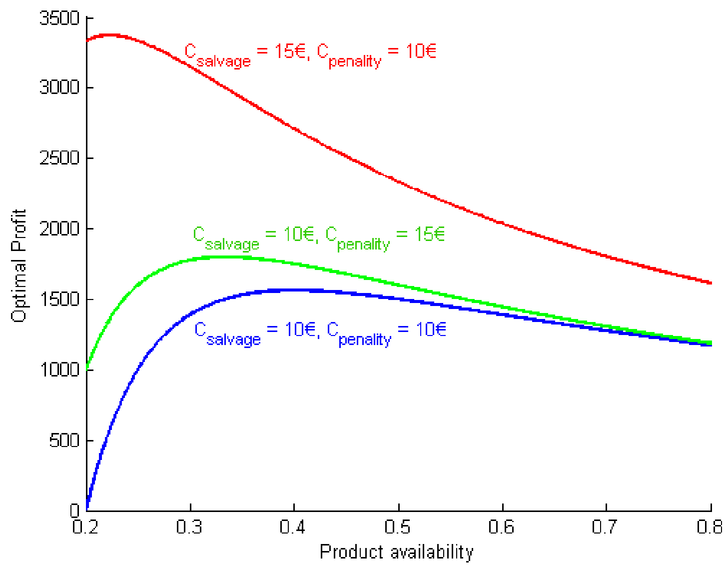


Figure 4.7: Optimal order quantity over product availability: Different product costs

When the penalty cost is lower than the unit cost of products, the vendor can order fewer products and can increase the profit because he will loss less money if stock-outs occur. Moreover, if the vendor can sell the remaining products at a salvage price higher than the unit cost, he can order more products because the salvaged products can increase profit.

We then integrated different RFID technologies to a simple inventory system. We consider that these technologies have different costs and performances. We analyzed the impacts of RFID technologies on a retailer inventory system. Order quantity that maximizes the profit and the profit depend on product characteristics, supply chain error rates, customer demands and RFID technologies (cost and efficiency).

In Figure 4.8, we illustrate how RFID technology (with unit cost of 0.3 €) affects the profit for different order quantities. We illustrate the profit over order quantity for the deterministic and stochastic cases. The parameters used in this figure are: C_{sell}=20 €, C_{buy}=10 €, μ_x=400, L_x=0, U_x=800 and μ_β=0.5. μ_θ=0.6 (without RFID), $\mu_\theta(0)$=0.6 (with RFID), σ_θ= 0.23 (without RFID, stochastic case), σ_θ= 0 (without RFID, deterministic case), $\sigma_\theta(0)$= 0.23 (with RFID, stochastic case) and $\sigma_\theta(0)$= 0 (with RFID, deterministic case).

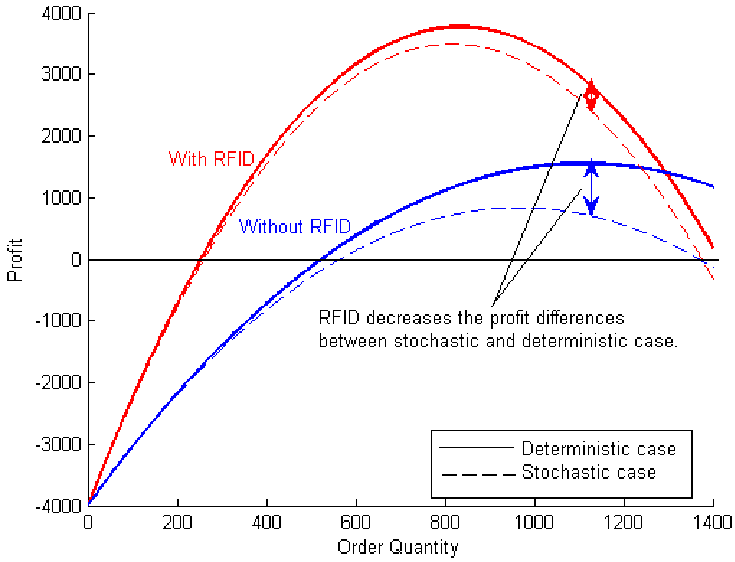


Figure 4.8: Profit over order quantity: With and without RFID, Deterministic and stochastic

Figure 4.8 shows that the vendor gains more with RFID technologies up to a specific order quantity. The cost of RFID technologies becomes larger if the vendor orders many products. Thus, for order quantities larger than this value, the vendor gains more without RFID. Hence, integrating RFID technologies is relevant up to a certain order quantity. This quantity depends on the costs of products and RFID technologies, and also the characteristics of the supply chain and the technologies.

Through figure 4.8, we can see that RFID technologies also reduce the negative impact of product availability variations. This figure shows that the profit in the stochastic case is closer to the profit in the deterministic case.

4.6 Conclusion

In this chapter we developed an analytical modeling to investigate how RFID technologies impact inventory management. We studied a single period inventory system in which inventory inaccuracy occurs because of thefts, misplaced items or unavailable items for sale. These errors cause unexpected stock-outs and lost sales. We first analyzed how these errors can affect the vendor order decision and the total profit. Some numerical experiments show that when product availability increases by 10%, the profit increases by 50% with a reduction of the optimal order quantity of 11%. We also assumed that the profit decreases with the variation of the error rates. The variation of product availability makes the systems unstable and difficult to manage. We then integrate RFID technologies to this inventory system. We consider that RFID technologies are not perfect, i.e. that their performances and costs can vary in a wide range. We observe that a critical RFID price exists for each product. This cost can vary with the product costs and the demand of the products.

The first originality of this chapter is that we combine several supply chain errors in the same model that makes this work close to the real stocking problems. We also consider, contrary to numerous papers in the literature, that RFID technologies are not perfect and their efficiency varies according to their costs.

In this chapter we studied a simple, single period inventory system for single product. However, practical systems are usually more complicated, dynamic and contain several products. We think that it would be interesting to extend our study by integrating more supply chain errors. Furthermore, we believe it would be relevant to extend our work by integrating multiple actors to each level of the supply chain to observe the interaction between the actors.

In the following chapter we will present a simulation study. Through analytical modeling we obtain interesting results. However, these models are limited to analyze complex and dynamic systems. Discrete event simulation is more appropriate to model such systems. In the next chapter, through simulations, we will try to analyze the impacts of RFID technologies on supply chain performances. We will also conduct ROI analysis to evaluate whether an investment is profitable on a specified period of time. We will develop ROI analysis through simulation studies to compare the benefits and costs of RFID integrations in supply chains.

CHAPTER 5

SIMULATION APPROACH: A THREE-LEVEL SUPPLY CHAIN

This chapter analyzes the impacts of RFID technologies on supply chain performances and economics through a simulation study. We consider various RFID systems with different costs and potential profits for different product types. We compare the impacts of RFID technologies by re-engineering supply chains using new possibilities provided by RFID technologies. Our simulation can be used as a decision support tool to evaluate whether RFID technologies are profitable in a specific supply chain by modifying simulation parameters.

Part of this chapter was presented in [121] (*Winter Simulation Conference 2008*) and [122] (submitted for publication in the Journal *Production and Operations Management*).

5.1 Introduction

In this chapter, we present a simulation study of a three-level retail supply chain. This supply chain includes a manufacturer, a distribution center and a retailer. In this chain, inventory inaccuracy occurs because of shrinkage errors such as thefts, misplacements or unavailable items for sale and delivery errors. This inaccuracy leads to stock outs, lost sales, long delivery times, poor customer satisfaction, etc. We aim to analyze how RFID technologies affect the supply chain performance. We first integrate various RFID technologies in retail supply chains with different tagging levels for a single product or multiple products. We then reorganize the supply chain using the new characteristics of these technologies. We use discrete event simulation to analyze the impacts of RFID technologies on the supply chain performances and to get the ROI (Return On Investment) for each case. The simulations were performed with the Arena Modeling Software [133] (Version 11).

Simulation methods are developed in order to observe the dynamic behavior of a system and to optimize its performances. Several authors use simulation approaches to analyze the impact of RFID technologies in supply chains. We present a complete state-of-the-art on this subject in Section 3.4.2. In surveying the literature on RFID technologies in supply chains, we found that all of the previous research focus on single-item modeling and also consider that RFID is a perfect technology that can continuously provide 100% accurate inventory levels. We also observe that there are few studies that focus on re-engineering supply chains through RFID technologies.

Contrary to most studies in the literature, in this chapter, we analyze the effects of different implementations of RFID technologies in a retail supply chain for different product types. We are interested in three different products which have different prices and customer demands. We consider that various RFID systems can be obtained by combining different tags, readers, frequencies, tagging levels and that the cost and potential profit of each system differ in a wide range. The main originality of this study is to compare the impacts of integration of different RFID technologies to supply chains by just replacing current identification technologies and by re-engineering supply chains using the new possibilities provided by RFID technologies. Our simulation can be used as a decision support tool by companies that are interested in evaluating whether RFID technologies are profitable for them by using the right parameters. Part of this study was presented in [121] (*Winter Simulation Conference 2008*) and [122] (submitted for publication in the Journal *Production and Operations Management*).

The remainder of this chapter is organized as follows. Section 2 describes the studied problem. In Section 3 a modeling of the current system is given. In section 4 we explain the integration of RFID technologies to this system. Supply chain reorganizations are studied in Section 5. Section 6 presents some general analyses and discussions. Finally, some concluding remarks and research perspectives are given.

5.2 Problem description

In this study, we consider a three-level retail supply chain with one manufacturer, one distributor and one retailer. The retailer level actually corresponds to two storage levels: the back store and the shelves.

Figure 5.1 represents the considered supply chain. End customers take a certain quantity of products from the shelves of the retailer. The retailer orders and receives the products from a distributor and stores them in its back store. The retailer can satisfy customer demands as long as items are available on the shelves. The inventory capacity of shelves is limited. Shelves are replenished under a reorder level policy or using the information of customers in out-of-stock situations. The distributor supplies the products from the manufacturer in order to satisfy the retailer demands. We assume that the manufacturer does not have product capacity constraints, and thus can always satisfy the distributor orders.

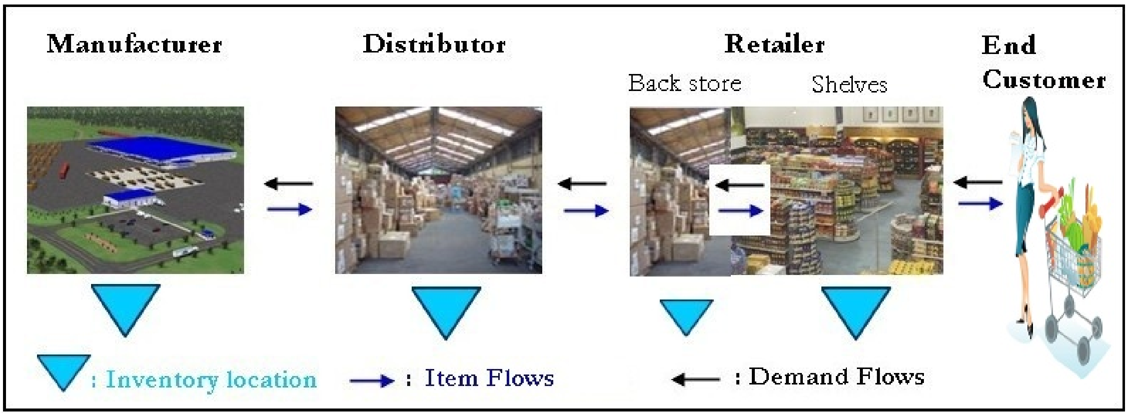


Figure 5.1: The studied supply chain

Several inventory errors may occur along the supply chain. In this study, we are mainly interested in shrinkage errors (such as thefts, misplacements and unavailable items for sale) and delivery errors. These errors induce inaccurate inventory information that influence supply chain performances by increasing stockouts, lost sales, delivery lead times, decreasing customer satisfaction, etc. Each actor controls its inventory levels by physical inventory counting to align physical and information system inventory levels. The frequency of physical counting is defined at each level depending on the properties of products, density of inventory inaccuracy in the system and counting time and cost.

5.2.1 Products

Three products will be analyzed, with different prices and different customer demands, as shown in Figure 5.2. In order to analyze their importance, we used the well-known ABC classification method. The classification of items is performed on their annual dollar value. There are three groups of items; A (very important), B (moderately important) and C (less important). The number of products in each category varies from one company to another. For more information, readers are referred to [130]. In what follows, the studied products A, B and C are respectively in the groups important, moderately important and less important.

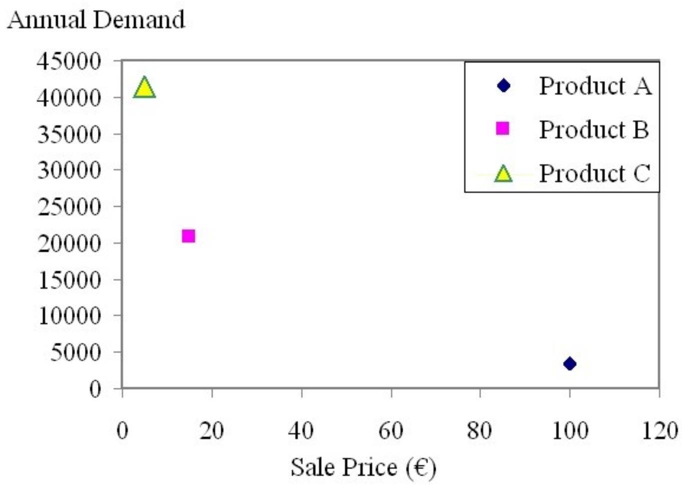


Figure 5.2: Demands and prices for products A, B and C

5.2.2 Order policy

The retailer and the distributor use a reorder point (s) and an Economic Order Quantity (EOQ) replenishment policy in order to satisfy end customer demands with a minimum holding and transportation costs. Equation 5.1 recalls the classical formula for the reorder point. The reorder level consists of the average demand during the lead time (average daily demand multiplied by the lead time) plus the safety stock. The safety stock is the extra inventory carried for protection against possible stockouts because of the variability of demands and/or lead times.

$$\text{Reorder point} = \text{Average lead time} * \text{Average demand} \; + \; \text{Safety stock} \qquad (5.1)$$

Equation 5.2 recalls the formula for the Economic Order Quantity (EOQ). The EOQ depends on the setup cost, the demand and the inventory carrying cost.

$$\text{EOQ} = \sqrt{\frac{2 * \text{Setup cost} * \text{Annual demand quantity}}{\text{Annual carrying cost}}} \qquad (5.2)$$

The values of the reorder point s and Economical Order Quantity EOQ calculated for products A, B and C are shown in Table 5.1. These parameters influence the supply chain performance. We believe that changing these parameters may be important for the supply chain performances. Hence, other values will be considered in Section 5.5.

Products		A	B	C
Shelf	s	1	2	4
	EOQ	6	20	50
Back store	s	10	50	100
	EOQ	140	1000	2600
Distribution Center	s	20	100	200
	EOQ	440	3050	8300

Table 5.1: Reorder points (s) and Economic Order Quantities (EOQ) for products A, B and C

5.3 Modeling a three-level supply chain

In this section we model the problem described in Section 5.2 by giving the simulation parameters. We believe that each parameter can influence the performance of the system and that experimenting various sets of parameters could thus be important for the analyses of our simulation study.

5.3.1 Customer demand

The retailer is open 288 days per year from (9h00 to 21h00), and customers arrive at the store to pick products A, B or C. The time between arrivals are exponentially distributed with means of respectively 60 min., 10 min. and 5 min.

The customer who arrives at the store goes to the shelves to search for the product. If the customer finds the product on the shelves, he takes it and goes to the cashier to purchase it. When stockouts occur on shelves and the customer cannot find the product, he can either leave the store without buying the product or look for an employee to ask for shelf replenishment. Customers can either wait until the shelves are replenished or give up after waiting a certain time (maximum 10 min.). The percentage of customers ready to wait for replenishment is different for each product (60 % for A, 50 % for B and 40 % for C). Table 5.2 gives the customer demand simulation parameters for products A, B and C. In the initial model, we use this set of parameters. Changing these parameters can influence the supply chain performances. This is why other sets of parameters will be considered in Section 5.5.

Products	A	B	C
Customer demand period (min.)	60	10	5
Customer maximum waiting time (min.)	10	10	10
Customer waiting for shelf replenishment rate (%)	60	50	40

Table 5.2: Simulation parameters for products A, B and C: Customer demand

Physical (PH) inventory levels on the shelves decrease when customers take products, but Information System (IS) inventory levels on the shelves only decrease when customers pay at the cashier.

5.3.2 Stock replenishment

The retailer automatically replenishes the shelves according to the IS inventory levels. The retailer may not automatically detect the errors if products lack on the shelves. As already mentioned, when stockouts occur on shelves, customers can search for an employee to request the product. If a customer finds an employee, the corresponding shelf can thus be replenished through the information given by the customer to the employee.

The shelves can be replenished as long as the items are available in the back store. Replenishment time is normally distributed with a mean of 11 minutes and a standard deviation of 2. After each shelf replenishment, the retailer decides to order products under a (s, EOQ) inventory policy based on the IS inventory levels.

The procedure in the distribution center is similar to the one in the back store. Products are automatically ordered from the manufacturer under a (s, EOQ) replenishment policy in order to satisfy the retailer orders. The delivery time is normally distributed with a mean of 2 days and a standard deviation of 0.2.

We assume that the manufacturer has no production capacity constraint, and thus can always deliver the products to the distribution center. The delivery time is normally distributed with a mean of 4 days and a standard deviation of 0.4. Table 5.3 gives the stock replenishment simulation parameters of the shelves, back store and distribution center for all products.

Products replenishment time	Shelf	Back store	Distribution center
Mean	11 min.	2 days	4 days
Standard deviation	2 min.	0.2 day	0.4 day

Table 5.3: Simulation parameters for products A, B and C: Stock replenishment

5.3.3 Physical inventory control

The retailer and the distributor update their IS inventory levels when they get stockouts or through a physical inventory control that they perform every period of a given duration. The frequency of the inventory control depends on the product, the density of inventory inaccuracy in the system and the counting time and cost, etc. Stock control processes at each inventory location are realized periodically. Table 5.4 gives these inventory control simulation parameters of the shelves, back store and distribution center for all products. Inventory control time depends on the inventory level and the size of products. In our study, we consider that stock control times are normally distributed. Supply chain actors try to find the optimal stock counting period under time and costs constraints.

Inventory control	Store	Back store	Distribution center
Stock control period	28 days	56 days	72 days
Mean of the stock control time	3 hours	6 hours	6 hours
Standard deviation of stock control time	0.3 hour	0.6 hour	0.6 hour

Table 5.4: Simulation parameters for products A, B and C: Inventory control

5.3.4 Supply chain errors

In this model we consider that different supply chain errors can occur such as shrinkage errors (thefts, misplacements or unavailable items for sale) and delivery errors. These errors induce a difference between the physical (PH) inventory levels and the Information System (IS) inventory levels that can lead to stockouts.

5.3.4.1 Shrinkage errors

Shrinkage errors (thefts and misplacements) can occur in the store because of customers. Figure 5.3 presents the customer buying process in the store. The customer who arrives at the store goes to the shelves to search for the product. If the customer finds the product on the shelves, he takes the product and then can act in three ways. He can go to the cashier to buy the product (satisfied customer), he can change his mind while shopping and put the product on another shelf in the store (misplacement) or he can steal the product (theft). If the customer does not find the product, he can either leave the store without buying the product or search for an employee to ask for shelf replenishment.

Because of stolen, misplaced and unavailable items for sale, inventory information becomes inaccurate. The same errors also occur in the back store. In this case, we consider that products can be misplaced or stolen by employees. Hence, there may be stockouts in the back store, which can increase the shelf replenishment delay and lead to the loss of customer sales. In the distribution center, the same errors can occur. These errors are generally caused by the distributor employees. Again, stockouts may happen because of these potential errors. The simulation parameters of these errors are fixed as in Table 5.5. These parameters depend on several factors, such as the characteristics of products and supply chains. In this study we focus on this set of parameters. We believe that experimenting other sets of parameters can influence supply chain performances.

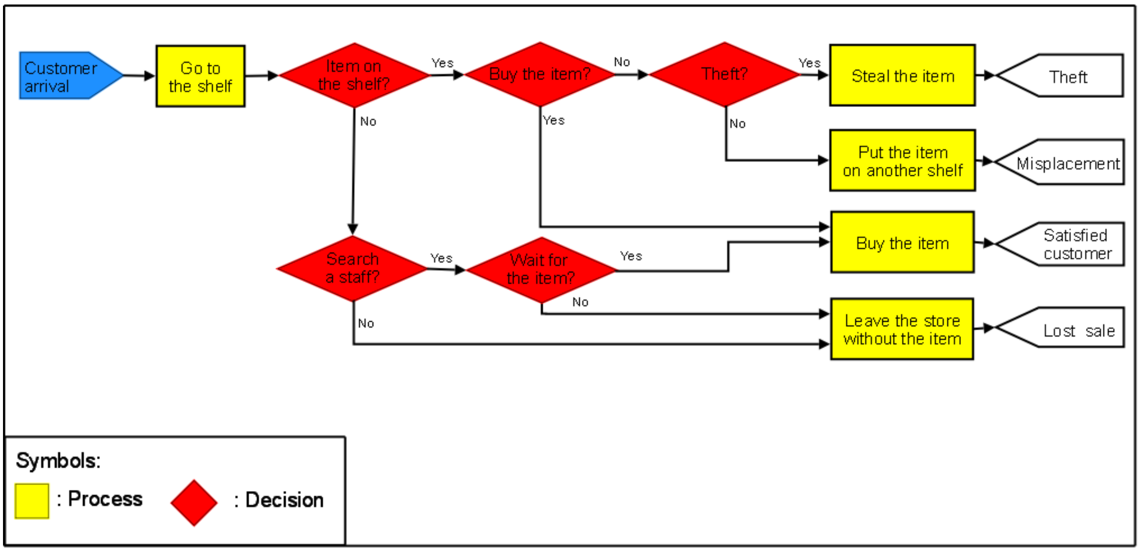


Figure 5.3: Customer buying simulation process

Products		A	B	C
Theft periods (days)	Back store	90	20	50
	Distribution center (days)	90	20	50
Misplacement periods (days)	Back store	90	15	50
	Distribution center (days)	90	15	50

Table 5.5: Simulation parameters for products A, B and C: Shrinkage error periods in the back store and distribution center

5.3.4.2 Delivery errors

Delivery errors are other types of supply chain errors that can cause stockouts. Delivery errors can happen between each inventory location. Supply chain actors order products to their supplier through a $(s,\ Q)$ inventory policy using the IS inventory levels. The manufacturer delivers the products to the distributor, the distributor delivers to the retailer, and the products are “delivered" from the back store to the shelves. We consider that delivery errors can occur in two main ways; during planned delivery processes and because of unplanned delivery processes. Figure 5.4 presents different types of delivery errors considered in the model and the decisions taken by actors against these errors.

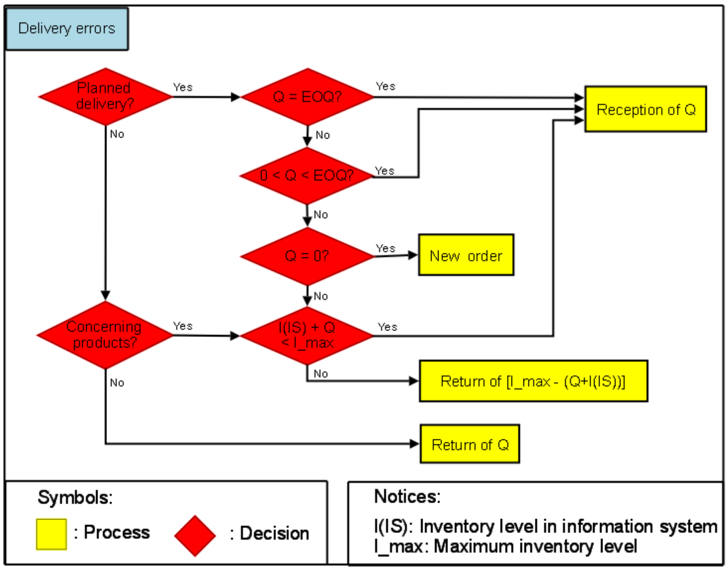


Figure 5.4: Delivery errors

a) During planned delivery processes

When an actor orders products (EOQ) to its supplier, there are four possibilities; he can receive exactly EOQ products, he can receive less products than requested ($Q < EOQ$), he can receive more products than requested ($Q > EOQ$), or he does not receive any product after a certain waiting time. In this model, we consider that the quantity due to the error ($|EOQ - Q|$) is uniformly distributed between 0 and ($EOQ/2$).

We assume that actors cannot always detect the errors. In this study, we consider that the error detection is uniformly distributed between the error detection rate and 1. If an actor does not notice the difference of quantity, he considers that he received the ordered quantity (EOQ). The error detection parameter is given in Table 5.6. It would be interesting in future studies to experiment the system with different values of this parameter.

The actors can react to these errors only if they can capture the errors. When an actor receives EOQ products, there is no error, he accepts the received quantity. Similarly, he will accept the received quantity if it is smaller than EOQ. In order to correct the error, the actor may order earlier the next delivery. When he receives more products than EOQ, he has to make a decision to accept or not the products in excess. If the sum of the actual inventory level (IS) and the received products ($Inventory\ level(IS) + Q$) is lower than the maximum stock level, he will accept the received quantity (Q). If this value is larger than the maximum stock level, he will return the products in excess ($Maximum\ stock\ level - (Inventory\ level(IS) + Q)$). Each actor has already defined the maximum stock level for each product.

Another delivery error can occur if the supplier loses the order. If the actor does not receive any product after a certain waiting time, he will cancel the order and make a new order. Maximum waiting times (see Table 5.6) have been defined for each actor according to the mean of delivery times.

Error detection rate		0.25
Maximum waiting time for the delivery	Back store	8 days
	Distribution center	32 days

Table 5.6: Simulation parameters for products A, B and C: Delivery errors

b) Unplanned delivery processes

These errors can occur because of suppliers. They can deliver by mistake some products although their customers did not order the products. There are different possibilities; the delivered products can interest the customers, or the products do not concern the customers. If the customer is interested, he can accept products according to his stock level. If the sum of the stock level and the received products is below the maximum stock level, he will accept the received quantity of the products. If this value is above the maximum stock level, he will return the products in excess. If delivered products do not interest the customer, he will refuse the delivery.

5.4 Integrating RFID technologies in supply chains

In order to analyze the impact of RFID technologies on supply chains, we integrate different RFID technologies to the current system. We focus on five different RFID technologies; closed loop RFID, case level RFID, item level RFID, item level RFID with more readers and finally item level RFID with smart shelves. In this section, RFID technologies are considered to replace the current identification system (i.e. bar codes). Six scenarios to simulate are defined to evaluate the impact of various implementations of RFID technologies.

5.4.1 Scenarios

Scenario 1

In the first scenario, a classical bar coding technology is used to identify the products. This scenario correspond to the current system.

Scenario 2

We integrate a closed loop RFID technology in the second scenario. Reusable boxes containing RFID tags are used only during the delivery process between manufacturer, distributor and retailer and are sent back to the initial sender. We consider that they can hold 10 items of product A, 50 items of product B or 100 items of product C, and there are 175 boxes for product A, 244 boxes for product B and 238 boxes for product C. The number of boxes is calculated in order to ensure that all deliveries can be realized at the same time. In this study, we use this set of parameters. However, these parameters may influence the supply chain performance. Hence it would be relevant to experiment other settings for these parameters in future studies.

The auto-ID technology in this scenario can improve the visibility and traceability of products during the deliveries from the manufacturer to the retailer and can decrease delivery errors. However, the visibility of items in stocks does not change. Thus, this technology can only reduce delivery errors.

Scenario 3

In the third scenario, RFID technology is integrated at case level tagging. Cases are prepared at the manufacturer and each case can contain 20 items of product A, 100 items of product B or 200 items of product C. The technology in this scenario can improve the visibility and the traceability of cases from the manufacturer to the retailer. It can decrease delivery errors and can reduce shrinkage errors in the back store and the distribution center. However, this RFID technology cannot affect the shrinkage errors in the stores, because cases are opened in the back store to replenish shelves. In this scenario, RFID technology cannot identify products outside cases. Thus, the visibility of items in the store does not change and the retailer still has the same errors in the store. On the other hand, since RFID technologies accelerate the physical inventory control; supply chain actors can increase the frequency of physical inventory controls to adjust inventories in the back store and the distribution center. This technology can thus deal with delivery errors and shrinkage errors in the back store and the distribution center.

Scenario 4

In the fourth scenario, we integrate RFID at item level. The visibility of items also improves in the store, where the number of errors is reduced and inventory levels can be checked frequently in the whole supply chain. Thus, this technology can scope with all delivery and shrinkage errors.

Scenario 5

As mentioned before, various RFID systems can be obtained by combining different tags, readers, frequencies, levels of tagging, etc. The cost and the potential profit of each system may change. In the fifth scenario, we consider a more efficient RFID technology at item level integrating more readers than in Scenario 4.

Scenario 6

In the last scenario, we add smart shelves to Scenario 5. These shelves can frequently (e.g. every minute) control inventories. This technology thus provides real-time information at item level in the store. However, this technology cannot improve on delivery errors compared to Scenario 5.

5.4.2 Simulation design

All scenarios are simulated for each product separately for three years and are replicated 100 times. Table 5.7 shows the most important parameters of each scenario for product B. Thefts and misplacements in the store are respectively the percentages of the customers who steal or move products. The values of these percentages have been chosen based on [48]. The second scenario can only decrease the delivery errors and increase delivery error detection. The number of stolen products decreases step by step from the second scenario to the last one. Misplacements in the store do not change because technologies cannot prevent customers to move items in the store. However, misplacements induced by employees in the back store and the distribution center, which follow a Poisson distribution, can decrease because RFID readers can guide employees to put products at the right place.

5.4.3 Simulation results and analyses

We first present the performance indicators that are used to analyze the impacts of RFID technologies on the studied models. The results are then analyzed separately for different cases.

Scenarios	**1**	**2**	**3**	**4**	**5**	**6**
Theft in the store (%)	2	2	2	1	0.5	0.5
Misplacement in the store (%)	1	1	1	1	1	1
Stock control period in the store (days)	24	24	24	4	2	1/1440
Mean of the stock control time in the store (hours)	48	48	48	12	12	1/2160
Mean of the theft period in the back-store (days)	1.5	1.5	2	2	3	3
Mean of the misplacement period in the back-store (days)	1.5	1.5	3	3	4.5	4.5
Right deliveries (%)	95	98	99.8	99.8	99.8	99.8
Wrong deliveries ($Q \neq EOQ$) (%)	2.5	0.5	0.1	0.1	0.1	0.1
Forgetten delivries (%)	2.5	0.5	0.1	0.1	0.1	0.1
Delivery errors detection (%)	0.5	0.9	0.9	0.95	0.95	0.95

Table 5.7: Varying simulation parameters: Product B

5.4.3.1 Performance indicators

To analyze the simulations, we measure key performance indicators such as the number of sales, lost sales (unhappy customers who leave the store without buying a product), lost products, the number of deliveries between the manufacturer, the distributor and the retailer, inventory levels of the manufacturer, the distributor and the retailer and the number and duration of physical inventory counting at each inventory location.

We analyze these performance indicators in order to answer two questions. How do RFID technologies affect supply chain performances and what are their economical impacts?

a) How do RFID technologies affect supply chain performances?

RFID technologies can improve operational processes such as reception, stocking, preparation, delivery, inventory counting, etc. They can also decrease supply chain errors. These improvements help to increase the number of sold products and decrease the number of unhappy customers who leave the store without purchasing the product by reducing stock outs.

The impact of RFID technologies can be evaluated using a customer satisfaction measure, such as the percentage of customers who actually purchase the product (satisfied customers) compared to the potential customers who want to purchase the product. Equation 5.3 shows how we calculate customer satisfaction indicator.

$$\text{Customer Satisfaction} = \frac{\text{Satisfied customers}}{\text{Lost Sales} \; + \; \text{Satisfied customers}} \tag{5.3}$$

b) What are the economic impacts of RFID technologies in supply chains?

In order to analyze the economic impact of each technology, the profits along the supply chain can be compared. We can calculate profits through income minus costs of stolen items and unavailable items for sale, delivery costs, inventory holding costs, inventory counting costs, technology costs and fixed costs. Equation 5.4 presents how we calculate the overall profit in the supply chain.

$$\begin{aligned} \text{Profit} \;&=\; \text{Income} \\ &-\; \text{Fixed costs} \\ &-\; \text{Costs of stolen items and unavailable items for sale} \\ &-\; \text{Delivery costs} \\ &-\; \text{Inventory holding costs} \\ &-\; \text{Inventory counting costs} \\ &-\; \text{Technology costs} \end{aligned} \tag{5.4}$$

Supply chain actors can gain as long as they sell products. Equation 5.5 shows the income, where Q_{sold} is the number of items sold in the chain.

$$\text{Income} = (\text{Selling price} \;-\; \text{Purchase price}) * Q_{sold} \tag{5.5}$$

Equation 5.6 shows how we calculate the cost of lost items, where Q_{lost} is the number of items lost in the supply chain because of theft and unavailable items for sale. If there are lost items in the system, actors would lose the buying prices of these products.

$$\text{Cost of lost items} = \text{Purchase price} * Q_{lost} \tag{5.6}$$

For each delivery, actors pay a delivery cost. Delivery costs increase for return deliveries that occur because of delivery errors.

$$\text{Delivery costs} = \text{Delivery unit cost} * \text{Number of deliveries} \tag{5.7}$$

There is a holding cost for every product stored in the supply chain.

$$\text{Holding costs} = \text{Holding unit cost} * \text{Mean of inventory level} \tag{5.8}$$

For each physical inventory control, actors may pay a cost depending on counting time and the number of employees used for counting.

$$\text{Counting costs} = \text{Counting unit cost} * \text{Counting time} * \text{Number of employees} \tag{5.9}$$

All parameters that are used to calculate the profit (Selling price, buying price, delivery unit cost, holding unit cost, counting unit cost) depend on the characteristics of products and of the supply chain. We define these parameters for the initial model as shown in Table 5.8. We believe that these parameters can significantly influence the profit of the supply chain. Hence, changing these parameters is important to evaluate the impacts of RFID technologies on supply chain profit. Different sets of parameters such as selling price, buying price, counting unit cost will be considered in section 5.5.

Products		A	B	C
Selling Price (€)		100	15	5
Buying Price (€)		60	10	3
Delivery unit cost (€)	Shelf	0.001	0.001	0.001
	Back store	50	50	50
	Distribution center	100	100	100
Holding unit cost (€)	Shelf	30	5	1
	Back store	18	2.25	0.6
	Distribution center	3.6	0.45	0.12
Counting unit cost (€)		50	50	50

Table 5.8: Profit function parameters: Products A, B and C

RFID technology integration has two main cost components; unit cost of RFID tags and fixed cost for technology implementation (antennas, manual readers, fixed readers, smart shelves, middleware, etc.). The costs that we use are shown in Table 5.9. Variable costs of RFID technologies depend on the unit cost of RFID tags (C_t) and the number of tagged items ($Number\ of\ boxes$ for closed loop RFID,

$Number\ of\ cases$ for case level RFID and Q_{total} for item level RFID). In our model we assume that we use the same type of tags for closed loop and case level RFID in Scenarios 2 and 3 and another type of tag for item level tagging in Scenarios 4, 5 and 6. The unit cost of RFID tags for the three products is fixed as 2 Euros for closed loop and case level RFID, and 0.2 Euros for item level RFID. Fixed costs of RFID technologies have been estimated, according to the RFID market, see [19].

	Variable cost (Euros)	Fixed cost (Euros)
Scenario 1	0	0
Scenario 2	$Number\ of\ boxes$	3000
Scenario 3	$Number\ of\ cases$	6000
Scenario 4	$C_t * Q_{total}$	8000
Scenario 5	$C_t * Q_{total}$	16000
Scenario 6	$C_t * Q_{total}$	60000

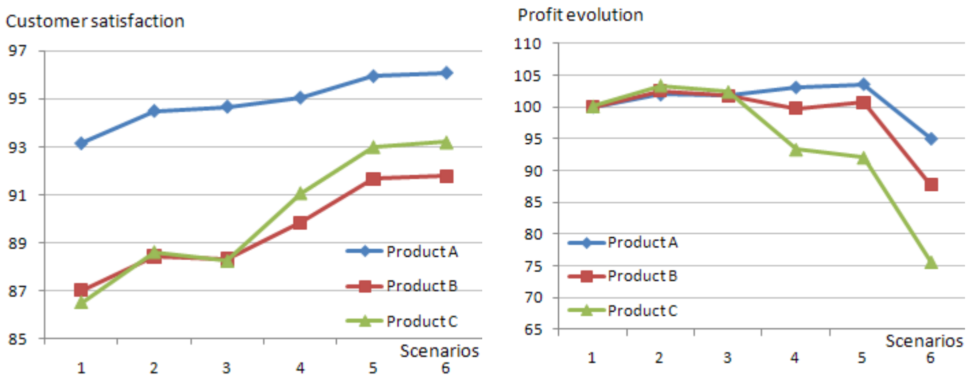
Table 5.9: RFID variable and fixed costs

5.4.3.2 Simulation results and analysis for products A, B and C

Figure 5.5 shows the variation of customer satisfaction and profit evolution (for a three-year simulation) according to the six scenarios. The customer satisfaction and the evolutions of profits in Figure 5.5 is reported for products A, B, and C. In order to observe the impacts of each RFID technology on the profits, we consider the profits of Scenario 1 as 100%, and the profits of other scenarios as a percentage of the evolution compared to the first one.

Figure 5.5a presents the customer satisfaction for products A, B and C. According to the simulation results, the number of sold products increases and the number of unhappy customers who leave the store without purchasing the product because of stockouts decrease from Scenario 1 to Scenario 6. This graph shows that the customer satisfaction for products A, B and C increases respectively from 93.2% to 96.1%, from 87% to 91.8% and from 86.5% to 93.2%. These results illustrate how RFID integration improves supply chain performances. In Figure 5.5a, it can be noted that there are two main changes in the customer satisfaction graph of all products; replacing bar codes with a closed loop RFID technology and also item level RFID integration.

Through figure 5.5b, we observe that a closed loop RFID integration (Scenario 2) increases the profits for all of the products. Profits of RFID technology integrations



(a) Customer satisfaction (%)   (b) Profit evolution

Figure 5.5: RFID integration: Products A, B and C

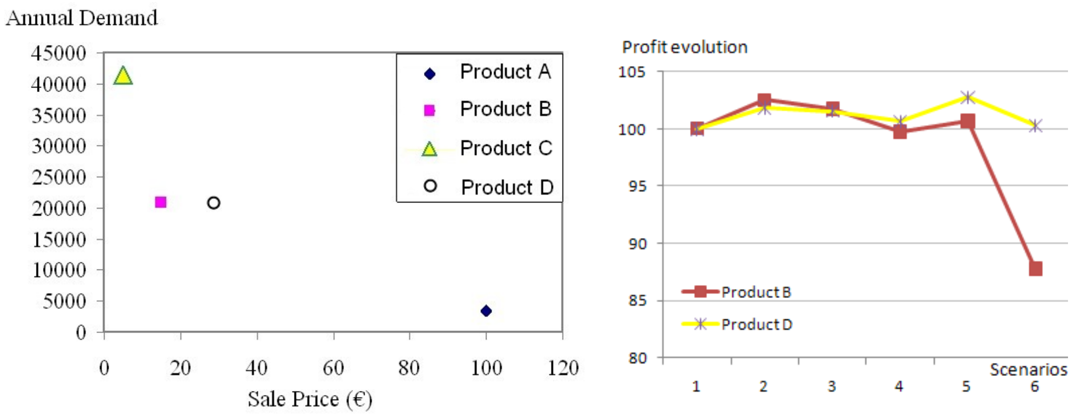
at the case level are very close to profits obtained by a closed loop RFID technology for all products A, B and C. However, this technology is less profitable for all products than with a closed loop technology. It can also be noted that RFID technology integrated at item level (Scenario 4) is profitable for products A, and B, although this technology cannot compensate its costs for a cheap product such as product C. Through figure 5.5b, we note that integration of a more efficient RFID technology (Scenario 5) increases the profits of each product. However, this technology is still not profitable for product C. Furthermore, we observe that, using smart shelves (Scenario 6) is not profitable for products A, B and C in three years. However, as mentioned before and as shown in Figure 5.5, this technology increases customer satisfaction through the increase of sales and the decrease of lost sales. Because of the high cost of smart shelves, the additional income does not compensate the technology costs.

We can conclude that:

> The impacts of RFID technologies depend on the technology characteristics (tagging level and cost).

5.4.3.3 Simulation results and analysis for expensive and highly demanded products

In order to analyze the economic impacts of smart shelves, we consider a new product D shown in figure 5.6a. It has the same demand rate and simulation parameters as product B (20,736 items/year) and is more expensive than B (selling price is 30 Euros).



(a) Demands and prices of product D (b) Profit evolutions of products B and D

Figure 5.6: RFID integration: Products B and D

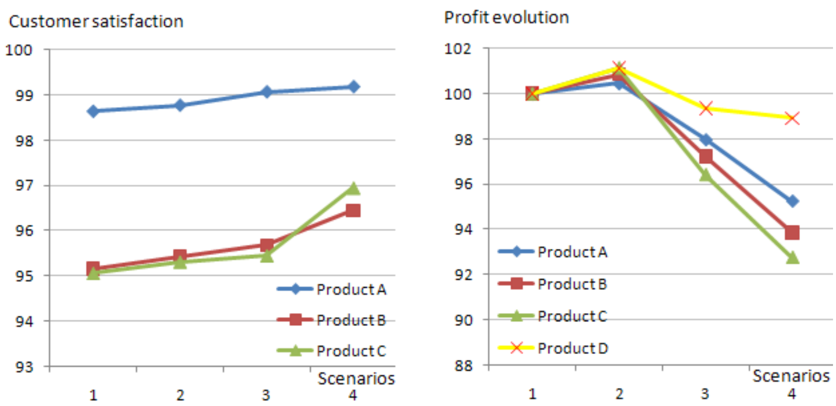
Figure 5.6b shows the profit evolution with RFID integration for products B and D. Through Figure 5.6b, it can be noted that Scenario 6 is more profitable for product D than for product B. Item level RFID with smart shelves is a very efficient technology that can provide real time information. However, due to its high cost, this technology cannot be integrated in all systems. Figure 5.6b illustrates the impacts of technology costs on the benefits of RFID technologies. Through this figure, it can be noted that smart shelves could be relevant for more expensive and highly demanded products. RFID technologies can more easily compensate the large integration investment for expensive products than for cheap products depending also on the level of customer demand. Through figure 5.6b, we observe that the most profitable technology for products B is a closed loop RFID (Scenario 2) while item level RFID in Scenario 5 is most profitable technology for product D.

We can conclude that:

The benefits of introducing RFID technologies depend on the product properties (demand and cost).

5.4.3.4 Simulation results and analysis of a supply chain in which only delivery errors occur

We consider a supply chain in which only delivery errors occur. We simulated Scenarios 1, 2, 3 and 4 for each product separately. Scenarios 5 and 6 are not simulated because the technologies used in Scenario 5 and 6 cannot decrease delivery errors more than in Scenario 4.



(a) Customer satisfaction

(b) Profit evolutions

Figure 5.7: RFID integration: Products A, B, C and D

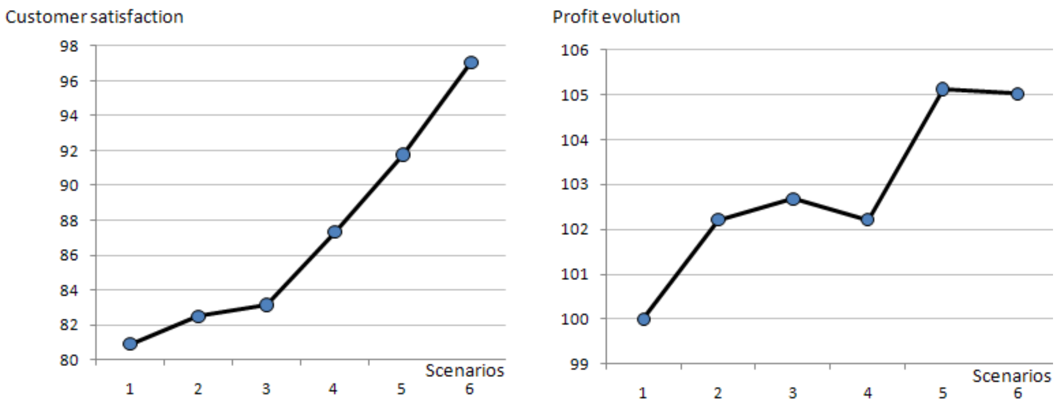
The graph of the evolution of profits in figure 5.7 is reported for products A, B, C and D. We observe that a closed loop RFID technology integration (Scenario 2) increases the profits for all products, whereas RFID technology integrations at case level and at item level (Scenarios 3 and 4) are not profitable for all four products. Even though these technologies increase the customer satisfaction as shown in Figure 5.7a, their contribution cannot compensate their costs for all products. Through this simulation, it can be noted that, for a supply chain in which only delivery errors occur, a closed loop RFID implementation is efficient and sufficient to increase profit.

We can conclude that:

The benefits of introducing RFID technologies depend on the supply chains characteristics.

5.4.3.5 Simulation results and analyses for multiple products

We analyze RFID impacts for a multi-product model. We simulate the three-level supply chain that contains shrinkage and delivery errors for products A, B and C together for three years. Figure 5.8 reports impacts of RFID technologies on the customer satisfaction and the profit for multiple products.



(a) Customer satisfaction of multiple products (b) Profit evolutions of multiple products

Figure 5.8: RFID integration: Multiple products

Figure 5.8a illustrates that RFID technologies increases the customer satisfaction by 16.2% for products A, B, and C together while the customer satisfaction is improved by 2.9 % for product A, 4.8 % for product B and 6.7 % for product C separately (see Figure 5.5a).

We remark that, as expected, RFID technologies increase profits more if they are used simultaneously for products. The profit increases by integrating an RFID technology in a closed loop scheme. Figure 5.8b shows that in a multi-product application, RFID technology with smart shelves (Scenario 6) increases profit by 2.5 % while this technology decreases the profit when each product is considered separately (see Figure 5.5b).

We can conclude that:

RFID technologies bring larger benefits if they are integrated in a supply chain for multiple products than for a single product.

5.5 Re-engineering supply chains through RFID technologies

The results of Section 5.4 shows that, by improving accuracy, efficiency and speed of processes, RFID technologies increase customer satisfaction, reduce operational costs such as storage, handling and distribution costs and increase sales by preventing some stockouts. Supply chains are actually designed and organized according to the properties of current technologies. New features of RFID technologies can help to get over more efficient supply chains by supporting their reorganization. We consider that the re-engineering of supply chains can be done at three levels; operational, tactical and strategic levels. In this section we analyze the impacts of RFID benefits on performances of re-engineered supply chains at operational, tactical and strategical level.

5.5.1 Re-engineering at operational level

Re-engineering supply chains at operational level consists modifying operation decisions that are taken weekly or daily. The objective of this type of reorganization is to optimize supply chain performances quickly and as cheap as possible through 'simple' modifications of operational decisions. We try to analyze how the reorganization of supply chains at operational level, such as reducing reorder point, can affect RFID benefits.

Reducing the reorder point (s)

As we mentioned before, the reorder point depends on the safety stock, and the safety stock is used to increase the stock level in order to prevent possible stockouts. Simulation results of integrating RFID technologies to the current supply chain shows that RFID technologies decrease supply chain errors and improve error detection that reduces stockouts. We can thus conclude that RFID technologies improve customer satisfaction with less safety stocks and thus lower reorder points.

In order to compare the benefits of RFID technologies on the re-engineered supply chain, we consider simulations of our initial model with reduced reorder points.

We reduce reorder points of back store and distribution center to evaluate the impacts of RFID technologies. Here, we use an experimental method to reduce the reorder points. However, we believe that for future studies, it would be relevant to apply optimization tools of Arena Modeling Software to find the optimal reorder points which maximize the profits.

Figure 5.9 illustrates a comparison of the profit evolution of products A, B and C between the supply chain with bar coding technology, a closed loop RFID integrated supply chain and a RFID integrated and re-engineered chain by reducing reorder points of back store and distribution center.

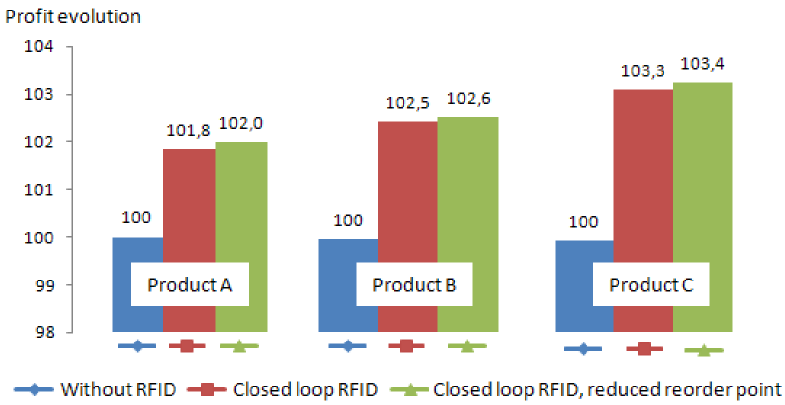


Figure 5.9: Reducing reorder point: Products A, B and C

Through Figure 5.9, it can be noted that reorganization the supply chain at operational level by reducing reorder points of the back store and the distribution center respectively by 25% and 16% improves profit by 0.2 %, 0.1 % and 0.1 % respectively for products A, B and C. The improvement obtained by reducing reorder points is not very large in percentage. However, since this “simple" re-engineering process does not require any investment, a profit increase of 0.1 % may still be significant in a supply chain.

We can conclude that:

> Supply chain re-engineering at operational level may increase benefits of RFID technologies.

5.5.2 Re-engineering at tactical level

This type of reorganization concerns mid-term planning decisions in supply chains. The objective is to improve supply chain performances with modifications of planning decisions. We analyze how modifications on planning decisions such as inventory control and order policy can affect RFID benefits.

5.5.2.1 Re-planning physical inventory control

As mentioned before, in supply chains, inventory levels in information systems and the real physical inventory levels often do not match. This misalignment can only be corrected through physical inventory controls. Stock control processes at each inventory location are realized periodically. The frequency of inventory controls depends in particular on the counting time and cost. Since inventory controls are easier and thus take less time using RFID technologies than bar-coding technologies, supply chain actors can increase inventory controls with RFID technologies.

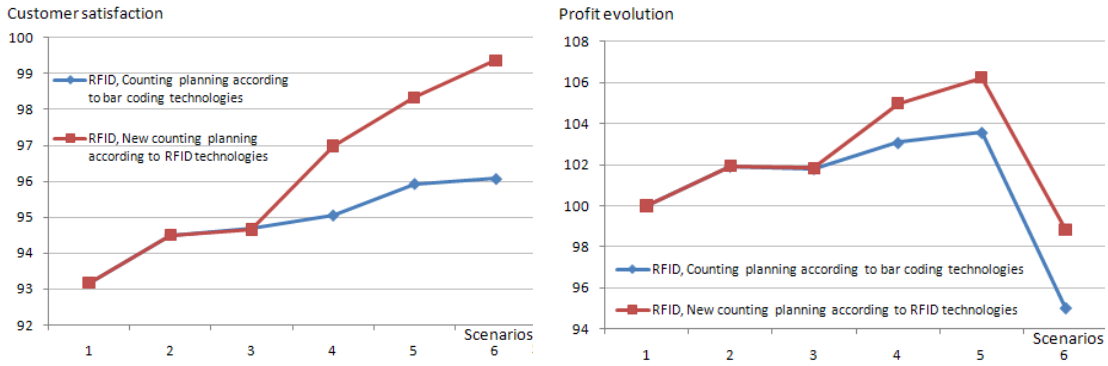
We propose stock control periods according to the stock control times of each technology. Table 5.10 presents the simulation parameters of stock counting processes.

Scenarios	**1**	**2**	**3**	**4**	**5**	**6**
Stock control period in the store (days)	28	28	28	4	2	≈0
Mean of the stock control time in the store (hours)	3	3	3	0.03	0.015	≈0
Stock control period in the back-store (days)	56	56	7	7	4	4
Mean of the stock control time in the back-store (hours)	6	6	0.6	0.6	0.3	0.3
Stock control period in the distribution center (days)	72	72	14	14	7	7
Mean of the stock control time in the distribution center (hours)	6	6	0.6	0.6	0.3	0.3

Table 5.10: Simulation parameters of stock counting processes

We simulate the re-engineered supply chain. Figure 5.10 shows a comparison of RFID benefits on customer satisfaction and profit between the current system and the re-engineered system for products A.

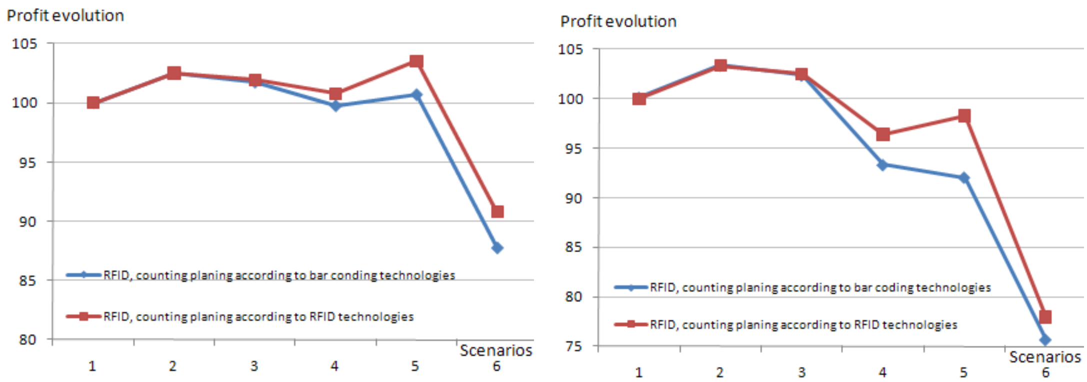
For item level RFID applications, Figure 5.10a shows that reducing stock counting periods improves the customer satisfaction of product A by 3% more than only integrating these technologies to the current system. Similarly, Figure 5.10b shows that optimizing inventory control periods increases profit of product A by about 2 % more than a simple integration for item level RFID technologies. Figure 5.11 shows the impacts of reducing stock counting periods on the profit evolutions for products B and C. Through this figure, it can be noted that reducing stock counting



(a) Customer satisfaction (b) Profit evolution

Figure 5.10: Different stock counting planning: Product A

periods by using the new properties of RFID technologies can significantly increase the profits of products B and C for item level RFID technologies.



(a) Profit evolution of products B (b) Profit evolution of products C

Figure 5.11: Profit evolutions of products B and C with different stock counting planing

We can conclude that:

Re-engineering supply chains at tactical level by re-planning inventory control can significantly improve the benefits of RFID technologies compared to just replacing current technologies.

5.5.2.2 Changing order policy

Order policies set the frequency and the quantity of deliveries between supply chain actors. They have a major influence on inventory levels along the supply chain and thus on customer satisfaction and profit. There are three main type of order policies; fix order time and order quantity, variable order time and fix order quantity, variable order time and order quantity. The system becomes more flexible through a policy with variable order time and order quantity. However, in this type of policies, the value of information significantly influences supply chain performances. Since RFID technologies provide real time information, order policy with variable time and variable quantity can be more profitable.

We consider an order policy with variable time and order quantity; order-up-to policy (s, S). In this policy, order is given when stock level is below the reorder point s. The objective of this policy is to complete the stock level to a certain up-to level S. The order quantity is calculated during each order by deducing the actual stock level from the up-to level. Table 5.11 shows the simulation parameters of this policy for products A, B and C.

Products	**A**	**B**	**C**
Reorder point of the shelf	1	2	10
Up-to level of the shelf	10	30	60
Reorder point of the back store	40	400	500
Up-to level of the back store	200	1200	3000
Reorder point of the distribution center	80	600	1000
Up-to level of the distribution center	600	3350	9000

Table 5.11: Simulation parameters: New order policy

We simulate 6 scenarios of the re-engineered supply chain model. Figure 5.12 shows the customer satisfaction and the profit evolution through two order policies for product A.

Figure 5.12a shows that, in a supply chain in which bar coding technologies are used to detect stock levels (Scenario 1), changing order policy from the (s, EOQ)

(a) Customer satisfaction for product A

(b) Profit evolution for product A

Figure 5.12: Different order policies: Products A

policy to the (s, S) policy decreases customer satisfaction by 20 %. However, this flexible order policy improves customer satisfaction more than the current policy when RFID technologies are integrated at item level.

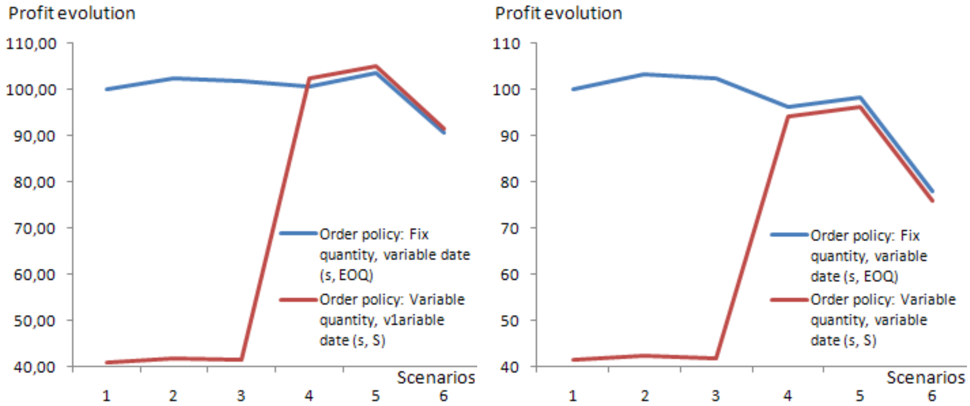
Through Figure 5.12, it can be noted that item level RFID increases the profit with the new order policy (s, S) by 1.5 % more than the current order policy (s, EOQ) for products A.

Figure 5.13 shows the profit evolutions through two order policies for products B and C.

Figure 5.13a shows that item level RFID increases the profit with the new order policy (s, S) by 1.5 % more than the current order policy (s, EOQ) for product B. Through Figure 5.13b, it can be noted that the new order policy increase considerable the profit with item level RFID applications for product C. However, this policy is still less profitable than the current policy for products with high demand.

We can conclude that:

Re-engineering supply chains at tactical level by changing order policy for not highly required products can significantly improve the benefits of RFID technologies.



(a) Profit evolution of product B (b) Profit evolution of product C

Figure 5.13: Different order policies: Products B and C

5.5.3 Re-engineering at strategic level

Re-engineering at this level corresponds to supply chain strategy or design decisions. Supply chain configuration, resource allocation, production capacity, inventory storage location, transportation modes are primary examples of such long-term decisions.

Removing back stores

In supply chains, inventory levels and storage locations are very important to satisfy customer demand and to increase total profit. Results of Section 5.4 shows that RFID technologies provide better visibility and traceability for products so that customer satisfaction and profit can be improved with less inventory. Figure 5.14 shows stock level evolution of products A, B and C in the back store according to the simulations performed in Section 5.4. We consider stock levels of the first scenario as 100 % and we analyze the evolution of stock levels with the integration of RFID technologies.

Figure 5.14 shows that RFID technologies decrease the stock levels of products A, B and C respectively by 12 %, 15 % and 30 %. RFID technologies improve the supply chain performances with lower stock levels in the back store. Fewer products in the back store may result in more space in the selling area in the store to improve sales. Since RFID technologies provide real time information on inventory and

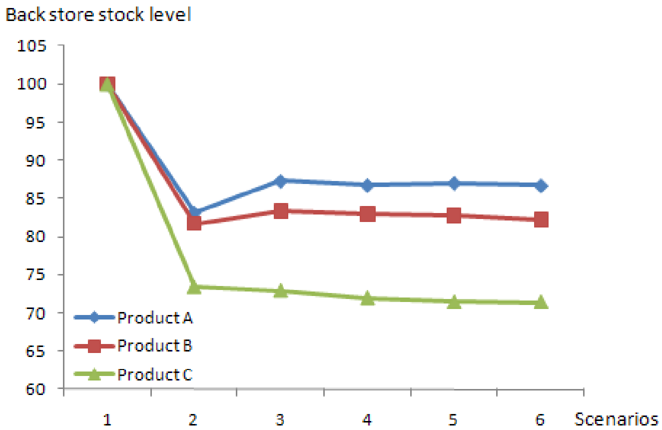
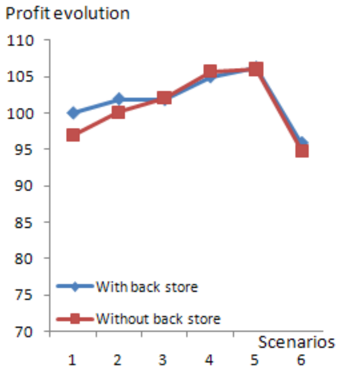


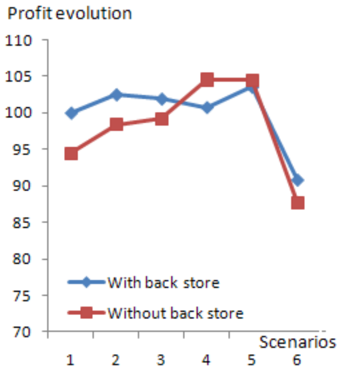
Figure 5.14: Stock levels of the back store: Products A, B and C

improve delivery processes, supply chains might be reorganized by removing back stores and using this area to increase the selling area in the stores.

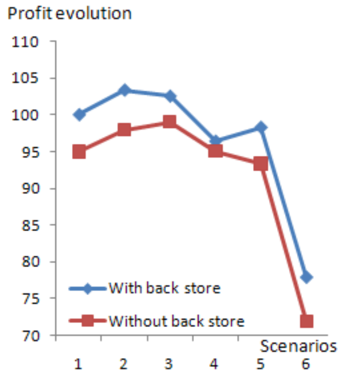
We model the studied supply chain without back store where the corresponding area becomes part of the store. We simulate this model for products A, B and C. Figure 5.15 illustrates the profit evolutions with and without back store for products A, B and C.



(a) Product A



(b) Product B



(c) Product C

Figure 5.15: Transforming back store as selling area: Profit evolution

Figure 5.15b shows that transforming back store as selling area increases the profit for product A by 1% and for product B by 4 % through item level RFID technology (Scenario 4). However, Figure 5.15c shows that removing the back store is not profitable for product C. Our simulation results show that removing the back store increases the profits of product A and B. It can be noted that the back store is necessary to prevent stockouts for products with large customer demand.

We can conclude that:

> Transforming back store as selling area with item level RFID technologies:
>
> - improve supply chain profits for products with average demand,
>
> - are not profitable for products with large demand.

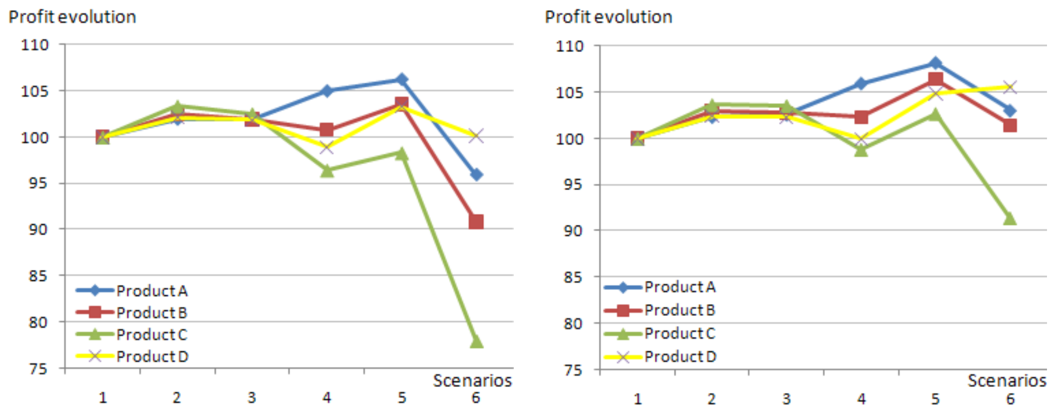
5.6 ROI (Return On Investment) analyses

The simulation results of Sections (5.4 and 5.5) show that RFID technologies provide multiple benefits for supply chains. However, actual RFID implementations require significant investments for companies because RFID systems are still considerably more expensive than current identification systems such as bar-coding. Hence, in order to decide to integrate these technologies in their systems, companies must perform relevant ROI analyzes to evaluate whether RFID applications are profitable.

In this section we use our simulation approach to evaluate in how long time RFID technologies can compensate the significant investment. We simulated each scenario separately for all products for different lengths of the time horizon (3 years and 5 years) in order to evaluate in which scenarios integrating RFID technologies become profitable.

5.6.1 ROI analyses of integrating RFID to the current supply chain

We analyze the ROI for the model of integrating RFID technologies to the current system. Figure 5.16 shows the profit evolution for products A, B, C and D for different horizons and for the 6 scenarios.



(a) Profit evolution for 3 years

(b) Profit evolution for 5 years

Figure 5.16: 3 years and 5 years simulation: Products A, B, C and D

Through Figure 5.16, we observe that RFID applications in all scenarios except the last one can be profitable for products A and B in three years. RFID implementation in Scenario 6 can compensate the costs of this technology and becomes profitable in three years only for product D while this technology becomes profitable also for products A and B in five years. It cannot always compensate the investment for products C even in five years.

We can conclude that:

> ROI analyses show that each integrating RFID technologies requires different time periods for different products to become profitable.

5.6.2 Critical costs of RFID technologies integrated to the current supply chain

We studied the economical impact of each technology in which the unit cost of RFID tags is set to 0.2 Euros for all products. For each scenario and for each product, a critical RFID tag cost could be calculated below which RFID technologies are profitable. We calculated the critical costs for each technology and for each product on a three-year horizon. The unit critical costs are shown in Table 5.12. They depend on incomes obtained through RFID technologies, the numbers of used tags and product prices. The values for Scenario 2 are very large because it considers a RFID technology at the case level and each case contains 100 products. The total number of required tags is considerably smaller than in the other scenarios. Note that the value for Scenario 4 for product C is zero because the associated technology cannot be profitable even if the unit tag cost is 0. Note also that, in all scenarios, the critical tag costs for product B are lower than for product A.

Products	A	B	C	D
Scenario 2	83.8	55.7	32.7	109.2
Scenario 3	1.2	0.2	0.04	0.15
Scenario 4	3.2	0.3	-	0.22
Scenario 5	3.9	0.6	-	0.52
Scenario 6	-	-	-	0.29

Table 5.12: Critical costs of RFID (Euros)

5.7 Conclusion

In this chapter, we simulated a three-level retail supply chain in which inventory inaccuracy occurs along the entire chain through shrinkage errors (such as stolen, misplaced or unavailable items) and delivery errors. This inaccuracy can affect supply chain performances by increasing stock outs, lost sales, and delivery times or by decreasing customer satisfaction.

We studied different RFID technologies with different tagging levels for various products which have different sale prices and different customer demands. We analyze the impacts of these RFID technologies on the actual supply chain performances and also on the performances of re-engineering supply chains.

Our simulation shows that RFID technologies integration by just replacing current technologies affects the supply chain performance and the profit at different ratios. Main factors which influence the impacts of RFID technologies are:

- Properties of RFID technology
    - o Tagging level

    - o Costs of the technology

- Properties of supply chain
    - o Supply chain errors
    - o Supply chain levels
- Properties of products
    - o Prices of the product
    - o Customer demand quantity

Simulation results also show that the benefits of RFID technologies can be improved by the reorganization of supply chains through new possibilities offered by technologies. This improvement depends on the organization level of re-engineering, RFID technologies properties, supply chains characteristics and product properties. The results of simulations show that:

- Supply chain re-engineering at operational level may increases benefits of RFID technologies.
- Re-engineering supply chains at tactical level by re-planning inventory control can significantly improve the benefits of RFID technologies compared to just replacing current technologies.
- Re-engineering supply chains at tactical level by changing order policy for not highly required products can significantly improve the benefits of RFID technologies.
- Transforming back store as selling area with item level RFID technologies:
    - o improve supply chain profits for products with average demand,
    - o are not profitable for products with large demand.

Additionally, we focused on ROI (Return On Investment) in order to evaluate how long companies have to wait to gain following RFID technology implementations. We also calculated the critical unit costs of the studied technologies that lead to positive profits. Again, the simulation results indicate that the ROI of various RFID applications depends on multiple factors especially the cost of technologies and products. The simulation results show that ROI analyses show that each integrating RFID technologies requires different time periods for different products to become profitable.

The originality of this chapter is that we compare the impacts of several RFID technologies by integrating them to current systems and by re-engineering supply chains through the possibilities offered by RFID technologies. Our simulation can be used as a decision support tool for companies that consider the integration of RFID technologies. By modifying the simulation parameters, various supply chains can be experimented.

In this chapter we studied a simple three-level retail supply chain. However, practical supply chains are usually more complicated. We believe it would be relevant to extend our work by integrating multiple actors at each level of the supply chain to observe the interaction between the actors. Furthermore, we think that it would be interesting to deal with practical cases in order to analyze more realistic data for our simulation approach; in particular on the unit and fixed costs of RFID technologies.

GENERAL CONCLUSION AND PERSPECTIVES

The research in this thesis is concerned with modeling and analyzing the impacts of RFID technologies on supply chain management. In the last few years, Radio Frequency IDentification (RFID) technologies have drawn considerable interests by supply chain actors. RFID technologies are considered to provide several advantages to supply chains in terms of efficiency improvements, value creation, such as increase of customer satisfaction or increase in revenue, and cost reduction, such as decrease of labor cost or reduction of inventory cost. Companies study the integration of these technologies in their systems to be able to get these benefits. However, integrating new technologies in supply chains often induces large costs. Furthermore, RFID technologies are still largely more expensive than current identification technologies. Thus, companies must conduct thorough analyses to evaluate the impacts of RFID technologies on supply chain performances and economics, in order to decide whether RFID technologies should be integrated or not, and to analyze how their benefits can be improved.

We started our research by providing a general overview of RFID technologies. We presented the working process, the challenges and the obstacles of applying RFID technologies in supply chains to develop basic knowledge of RFID technologies. We then reviewed and discussed the literature to propose an effective overview of the challenges and benefits related to integrating RFID in supply chains. Finally, in this dissertation we developed analytical and simulation approaches to evaluate qualitative and quantitative impacts of RFID technologies on supply chain performances and profits.

In the literature review of Chapter 2, we focused on the studies which deal with potential benefits of RFID technologies in supply chains. The literature is discussed according to two criteria; the problems which can be improved by RFID technologies and the methods which are used to analyze the impacts of RFID technologies. The cost reduction and value creation, particularly related to inventory inaccuracy, the bullwhip effect and replenishment policies are the main subjects on which we focused. The main methods which have been developed to analyze the impact of RFID technologies on supply chain management and economics are analytical models, simulations, case studies, experiments and ROI analyses. To the best of our knowledge, it is the first study which presents a complete review of the literature through statements and critical analyses of related publications and which develops an effective overview of the challenges and benefits related to integrating RFID in supply chains.

In the analytical approach of Chapter 3, we developed a mathematical model of a single-period inventory system in which inventory inaccuracy occurs because of thefts, misplaced items or unavailable items for sale. We first analyze the impacts of these errors causing unexpected stock-outs and lost sales on the profit of the inventory system. We then integrate item-level RFID to evaluate their benefits and costs on inventory management. Numerical analyses show that RFID technologies can improve supply chain performances and profits depending on product costs and customer demands. It can also be noted that a critical RFID price exists for each product to improve the total profit of supply chains. The originality of this chapter is that we combine several supply chain errors in the same model that makes this work close to real stocking problems. We also considered, contrary to numerous papers in the literature, that RFID technologies are not perfect and their efficiency varies according to their costs.

In Chapter 4, we analyzed the dynamic behavior of supply chains using discrete event simulation method. We are interested in a three-level supply chain for three types of products that have different prices and customer demands. We considered five RFID technology applications; closed loop RFID, case level RFID, item level RFID, item level RFID with more readers and finally item level RFID with smart shelves. We first analyzed the impacts of these technologies on the supply chain. Our simulation results show that these different RFID technologies can improve performances of the current system at different ratios depending on various factors such as the technology properties (tagging level or cost), product properties (the price or customer demand), supply chain properties (supply chain levels or errors), etc. We then proposed to re-engineer this supply chain at operational, tactical and strategic levels based on the opportunities offered by RFID technologies. We compared the impacts of several RFID technologies by integrating them to current systems and by re-engineering supply chains using new characteristics of RFID technologies. Simulation results show that re-engineering supply chains at strategic level such as the reorganization of storage locations can improve the benefits of RFID technologies more than “simply" integrating RFID technologies in actual supply chains. According to our knowledge, our simulation is the first study that introduces different RFID technologies in a complete supply chain. The originality of this study is also to compare the impacts of integrating different RFID technologies to supply chains by just replacing current identification technologies and by re-engineering supply chains using the new possibilities provided by RFID technologies. Our simulation can also be used as a decision support tool by companies that integrate RFID technologies.

Perspectives

To the best of our knowledge, our study is the first research on integrating different RFID technologies in a complete supply chain. We developed analytical and simulation models to evaluate qualitative and quantitative impacts of RFID benefits in supply chains. Results obtained in this dissertation highlight interesting perspectives for future studies.

In our research, we developed analytical models of a single-period inventory system for a single product. However, practical systems are usually more complicated; contain several products, several actors, several periods, etc. We think that it would be interesting to pursue our study by analyzing an inventory system that contains multiple products during several periods. It would be interesting to analyze the impacts of the interaction between multiple actors on inventory systems.

Our simulation study focuses on a “simple" three-level retail supply chain. We believe it would also be relevant to extend our work by integrating multiple actors at each level of the supply chain to evaluate the impacts of RFID technologies on information and product flows between the actors.

In our research, using a simulation approach, we analyzed the re-engineering of the supply chain on the impacts of RFID technologies on supply chain performances and economics. We consider changes in the supply chain at operational, tactical and strategic levels, such as reducing the order point, re-planning physical inventory control, changing order policy and removing back stores. In this study, we present our first reflections and results on the re-engineering of supply chains using new characteristics of RFID technologies. However, re-engineering can be realized in a wide range. We believe that it would be interesting to consider new re-engineering possibilities to improve the benefits of RFID technologies in supply chains; such as removing supply chain intermediate levels, changing payment processes, etc. In this dissertation, we use experimental methods to optimize the performance of supply chains to improve the benefits of RFID technologies. However, we believe that for future studies it would be relevant to apply optimization tools of Arena Modeling Software to find the optimal reorder points which maximize the profits.

Our research is based on the real-world problematic of supply chains and RFID market characteristics. However, we consider theoretical methods to evaluate RFID impacts on supply chain management. We believe that theoretical analyses must be completed with practical analyses by conducting real implementations in actual industry environments to understand the technical feasibility of RFID technologies and to validate the integration of RFID in the complete system and the redesign of the system through these technologies. Pilot projects can be relevant to test these technologies in a small and simplified environment to observe the difficulties and the efficiencies of their integration and to support the re-organization of supply chains through new features of RFID technologies.

According to our knowledge, most of the RFID works have focused on logistics and inventory management applications. However, we believe that RFID technologies provide significant benefits on the total product life cycle beginning from manufacturing and including after-sale service processes. Particularly, RFID technologies provide huge advantages for after-sale services compared to current identification technologies. Through RFID technologies, all manufacturing and operational information of a product can be recorded during its life cycle and also after sale. This information could help to recognize the causes of potential failures in advance and thus support maintenance activities. The detailed information can also help to determine the parts of the product to be recycled, or disposed. RFID technologies can thus support product recycling and the disposal of hazardous materials. It would thus be interesting to evaluate the impacts of RFID technologies on the management of after-sale services and on product recycling processes.

Our study is the first research on RFID technologies in supply chains that was carried out in the Department of "Sciences de la Fabrication et Logistique (SFL)" of the Center for Microelectronics of Provence of the Ecole Nationale Supérieure des Mines de Saint-Etienne. We believe that this study provides a complete overview of supply chains that allows to analyze various chains by focusing on their specific constraints. Thus, we considered that our research is a key study that can be extended for numerous applications in various supply chains, such as assembly manufacturing, after-sale service support, maintenance applications in healthcare, pharmaceutical, textile and luxury goods industries, etc. Our study is pursued by various research projects in the SFL Department such as RFID technologies in health care systems

(PhD thesis of S. Housseman), integrating RFID technologies and GPS systems in distribution (PhD thesis of L. Haouari) and maintenance activities in the aeronautics industry (PhD thesis of C. Jimenez).

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Curriculum Vitae

Aysegul Sarac was born in Mersin, Turkey (1981). She studied industrial engineering at the *Galatasaray University* and received her bachelor degree in 2005. In 2006, she received her master degree in management from *INP-Grenoble* in France. From November 2006, she started her Ph.D research at "*Ecole des Mines de Saint-Etienne*" in France. Her Ph.D research focuses on modeling and decision making support for introducing RFID technologies in supply chains, which has resulted in a number of published articles scientific journals such as "*International Journal of Production Economics*" and "*Production and Operations Management*". She has also given presentations on her research in international conferences in both Europe and North America such as "*Winter Simulation Conference*", "*International Conference of Modeling and Simulation*".

MODELISATION ET AIDE A LA DECISION POUR L'INTRODUCTION DES TECHNOLOGIES RFID DANS LES CHAINES LOGISTIQUES

Résumé:

Les technologies RFID présentent des avantages non négligeables en comparaison aux technologies d'identification actuelles. Cependant, l'intégration de ces technologies dans les chaînes logistiques implique souvent des coûts élevés. Ainsi, les entreprises doivent conduire des analyses poussées pour évaluer l'impact des RFID sur le fonctionnement et l'économie des chaînes logistiques et décider de l'intégration ou non de ces technologies.

Dans cette thèse nous nous concentrons sur la modélisation et l'analyse de l'introduction des technologies RFID dans les chaînes logistiques. Nous présentons d'abord une information générale sur les technologies RFID. Nous analysons ensuite la littérature sur l'intégration des RFID dans les chaînes logistiques en focalisant sur les défis et les avantages liés à l'intégration de ces technologies. Nous développons deux approches (analytique et par simulation) afin d'évaluer les impacts qualitatifs et quantitatifs des technologies RFID sur le fonctionnement et le profit des chaînes logistiques. Nous développons aussi une analyse du retour sur investissement (ROI), pour comparer les revenus obtenus à l'aide des technologies RFID avec les coûts associés à leur intégration. D'autre part, nous nous intéressons à l'amélioration des avantages de RFID dans les chaînes logistiques. Nous comparons les impacts de l'intégration de différentes RFID dans les chaînes logistiques par un remplacement simple des technologies d'identification actuelles et par la réorganisation des chaînes logistiques utilisant les nouvelles possibilités des technologies RFID. Les résultats obtenus dans ce travail mettent en évidence des perspectives intéressantes pour des études futures.

L'originalité de cette étude est que nous comparons les impacts de plusieurs technologies RFID en les intégrant aux systèmes actuels et en reconstruisant des chaînes logistique grâce aux possibilités offertes par des technologies RFID. Notre modèle de simulation à événements discrets peut être utilisé comme un outil d'aide à la décision pour les sociétés qui visent à intégrer des technologies RFID.

Mots Clés:

RFID, chaine logistique, modèle analytique simulation par évènements discrets, réorganisation

MODELING AND DECISION SUPPORT FOR INTRODUCING RFID TECHNOLOGIES IN SUPPLY CHAINS

Abstract:

In the last few years, RFID technologies have drawn considerable interests as one of the possible solutions to overcome these supply chain problems. However, integrating these technologies in supply chains induces large costs. Thus, companies must evaluate the impacts of RFID technologies on supply chain performances and economics, in order to decide whether these technologies should be integrated or not.

In this thesis we focus on modeling and analyzing the impacts of introducing RFID technologies in supply chain. We first provided a basic knowledge of RFID technologies that includes the working process, the challenges and the obstacles of applying RFID technologies in supply chains. We then reviewed the literature and discussed the challenges and benefits related to integrating RFID in supply chains. Finally, we developed analytical and simulation approaches to evaluate qualitative and quantitative impacts of RFID technologies on supply chain performances and profits. We also developed ROI (Return On Investment) analysis, to compare the benefits obtained by RFID technologies with the costs associated to the integration of these technologies. Furthermore, we focused on how the benefits of RFID technologies can be improved by re-engineering supply chains using the characteristics of RFID technologies. Results obtained in this thesis highlight interesting perspectives for future studies.

The main originality of this study is to compare the impacts of integrating different RFID technologies to supply chains by just replacing current identification technologies and by re-engineering supply chains using the new possibilities provided by RFID technologies. Our simulation can also be used as a decision support tool by companies that integrate RFID technologies.

Keywords:

RFID, supply chain, analytical model, discrete event simulation, re-engineering